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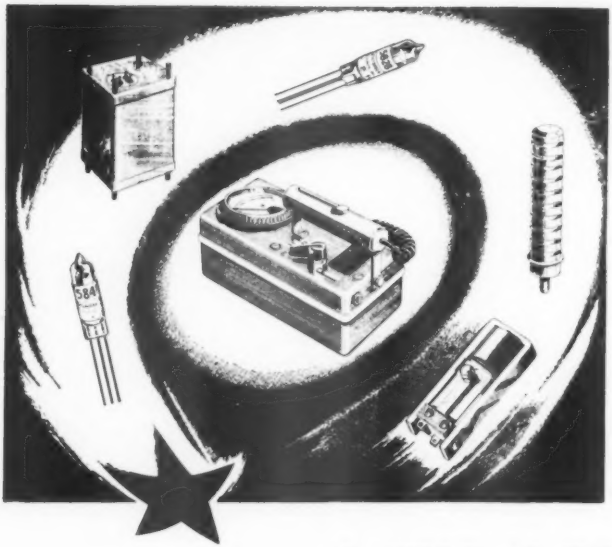

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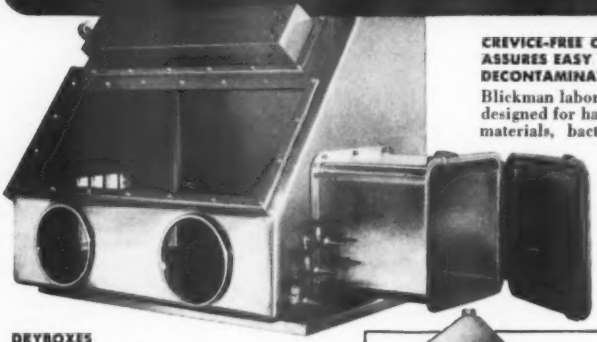

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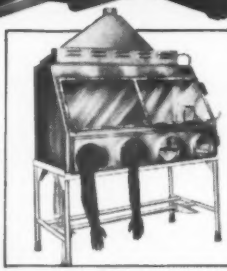

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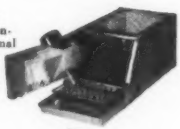

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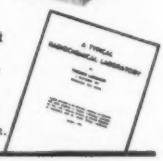

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Radioisotopes in Pharmaceutical and Medical Studies—I

NUCLEONICS takes pleasure in offering this first in a series of three articles that bring together a fund of both published and unpublished information to which workers in the field of isotopic medicine can relate their own research

By D. L. TABERN, J. D. TAYLOR, and G. I. GLEASON
Department of Special Research, Abbott Laboratories
North Chicago, Illinois

USES FOR RADIOISOTOPES in biology and medicine fall into three broad categories. They can be employed: (1) to investigate by the tracer technique not only the metabolism of drugs and natural products but also the complex processes of a biological nature; (2) to assist in the diagnosis of disease; and (3) to aid in the treatment of disease.

The degree to which isotopes assist in the solution of biologic problems rests largely upon the skill of the investigator. Unquestionably, isotopes are being used today in problems that could be answered equally well by older methods. It is also true, however, that cleverly designed isotopic experiments have supplied crucial data obtainable in no other way.

When we enter the fields of diagnosis and therapy, we automatically encounter an added restriction—namely, that the techniques must be applicable to human beings. Among the hundreds of isotopes known, one can find almost every conceivable range of radiation, half-life, and biological affinity. In addition, the skill of the chemist has contributed the possibility of combining certain isotopes in a wide variety of structural and chemical combinations.

These still largely unsolved problems can most effectively be illustrated and discussed in this series of articles in the appropriate sections. The topics to be covered are as follows:

1. *Uses of Iodine-131*
2. *Uses of Phosphorus-32*
3. *Tumor Localization*
4. *Other Diagnostic Agents*
5. *Tumor Therapy*
6. *Barbiturates and Thiobarbiturates**
7. *Sulfur Amino Acids**
8. *The Dynamic State**
9. *Membrane Permeability**
10. *Antigens and Antibodies**
11. *Fat Metabolism**
12. *Thyroid and Antithyroid**
13. *Metabolic Studies with Phosphorus-32**
14. *Isotopes as an Analytical Tool**
15. *Mechanical Tracing**
16. *Toxicity of Carbon-14**
17. *Drug Metabolism*†

Selection of these topics and references for this paper, while admittedly quite arbitrary, was based upon a desire to demonstrate the significant contributions which radioisotope studies have made to medical progress, while still remaining within the scope of the title of this paper.

To conserve space, rather than name all the individuals involved, reference

* Will be published in Part II of this paper to appear in the December NUCLEONICS.
† Will be published in Part III of this paper to appear in the January NUCLEONICS.

THE ABBOTT ISOTOPE PROGRAM . . .

In an effort to see how their organization could make worth-while contributions in the field of radiobiology and isotopic medicine, the scientific staff of Abbott Laboratories set out to prove three things to themselves and their company: *First*, that they could profitably use certain isotopic techniques and materials to gain a better understanding of the physiology and pharmacology of the drugs Abbott is now preparing; *second*, that, if the research clinician is to use isotopic drugs on human beings, they could make such drugs available to him in suitable form, doubly checked for purity, activity content, sterility, etc.; and *third*, that they could aid in research to augment the pitifully few useful radioactive preparations for diagnosis and therapy available today.

Although Abbott's executives knew that the supplying of isotopes for research and therapy might remain a "labor of love" for some time to come, they endorsed the program built on these three points and agreed to operate it as a research project.

Nominal service charges were set for preparing and distributing such supplies in the hope that increasing usage would some day make the work self-supporting. Laboratories were set up and equipped, and personnel given special training at Oak Ridge and elsewhere.

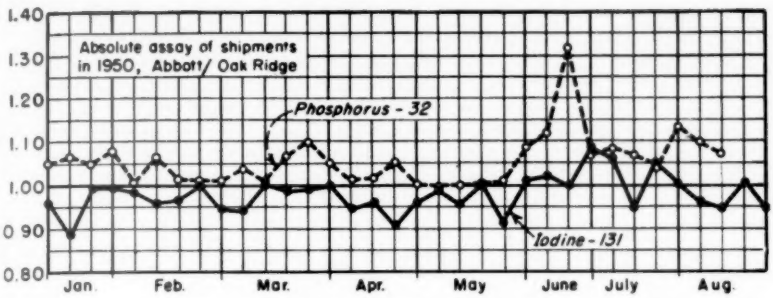
The Abbott staff looks upon the project as a cooperative venture, their part being to develop and supply materials and act as a clearing house for new information, ideas, and equipment. It was on this basis that much of the information presented in this series of papers was made available to them.

They early realized that a prosaic but nonetheless essential service to be rendered by a group such as theirs was the supplying of pharmaceutically correct solutions of such simple but widely used isotopes as P^{32}, I^{131}, etc. Materials coming from Oak Ridge are not sterile, have not been tested for pyrogens, and vary greatly in specific activity from batch to batch. To identify, dilute accurately, buffer if necessary, assay, and sterilize such solutions prior to use necessitates the maintenance of a "hot laboratory" (separated physically from the assay and therapy rooms) with specialized personnel. If such an operation is carried out only occasionally, it is obviously not economical for the infrequent user of isotopes to maintain such a facility. Abbott's hot-lab isotope processing for such a user, therefore, can be a real service to him.

Abbott, as a secondary distributor under arrangement with the Atomic Energy Commission, orders as a single shipment each week the amount it estimates as

has frequently been made to groups working on the indicated projects. For the same reason, only the more recent references in a series are given.

Space has also necessitated the elimination of at least four subjects which otherwise would have been covered, namely, first, the effect of radiation on biological systems; second, the treatment of radiation damage; third, metabolic studies involving carbohydrates and the lower fatty acids;



necessary to cover requests on hand and still have a moderate reserve. Thus far, the law of averages has worked and it has been possible for them to ship on sometimes as little as an hour's notice supplies urgently needed by authorized hospital groups. Special delivery to the airport and the use of air express and air freight permits next-morning receipt almost anywhere in the country. Small shipments, which vary from 25-30 millicuries to as few as the 2–3 needed for a single case, have resulted in the development of compact, hermetically sealed, shielded containers.

The contents being sterile and of known and relatively constant composition, the unit may be taken directly to the point of administration and all or part of the contents withdrawn by a syringe without opening the container or removing it from the lead shield. The container may then be simply set aside in a safe place until decay has brought any residual activity to the level recommended by the AEC for ordinary disposal. The request may specify a given dosage to be present on the expected day of administration, still further decreasing possibilities of error. Abbott has set up their own absolute-assay procedures on the basis of three different methods, quite independent of Oak Ridge. The chart above shows a comparison of Abbott assays with those stated by the Isotopes Division at Oak Ridge. The agreement is excellent, but the obvious exceptions only prove that slips can happen even with the best of care and that, for greatest safety, Oak Ridge assays should be checked again before such materials are used clinically.

Abbott acknowledges its obligation to collaborating groups to assist in assay procedures and to attempt, especially in cases of unusual isotopes such as Au^{198}, to keep a running check on values observed and the doses used by such groups.

A simple method for absolute beta counting that does away with the necessity for absolute standards has been devised by G. I. Gleason of the Abbott staff, and publication of it will be made soon.

and fourth, studies on photosynthesis. The third of these has just been admirably treated, especially from the standpoint of biologic mechanisms by Bernhard (*1*).

Within the past few months, a number of studies have been reported dealing with isotopes in dental problems. These will be the subject of a communication by another author in a subsequent issue of NUCLEONICS.

For a discussion of the production

and availability of isotopes, the reader is referred, in particular, to a report by Aebersold (*2*).

As we shall see, isotopic studies have firmly established the concept of the "metabolic pool," through which passes, at one time or another, a large portion of any given element (such as carbon, nitrogen, or sulfur) taking an active part in metabolism. Isotopes have, in turn, aided in unraveling the complex problems thus presented. A given lot of isotopic atoms, administered in the form of a given compound at a given time, is clearly distinguishable from all other atoms as long as it remains in the body. On the other hand, certain elements and compounds do not enter such a pool but are instead rapidly eliminated in their original form or as degradation products that are often capable of identification by isotopic means.

1. Uses of Iodine-131

Iodine-131 is the most widely used isotope and the one that has achieved the most practical success in actual clinical use. It has betas of 0.315 and 0.6 Mev, and gammas of 0.638, 0.636, 0.283, and 0.08 Mev. Radiation effects within the thyroid are predominantly due to the beta particles, but the gammas have the advantage of allowing measurements outside the body.

The most satisfactory vehicle for "dispensing" seems to be a slightly alkaline solution of essentially carrier-free material containing a trace of sulfite as a reducing agent. All glassware used in handling should be pretreated with cold iodide and thoroughly washed.

Iodine is being used extensively today for both the diagnosis and therapy of thyroid diseases. With tracer doses of 25–100 μc, hyperthyroids usually take up over 50% in 24 hours as contrasted with 10–20% for normals. These measurements can be made readily by means of a counter placed on the neck of the patient over the thyroid. The trend is toward going farther and studying actual conversion to protein-bound thyroxine, wherein hypothyroids give 6–10% conversion, hyperthyroids give over 50%, and thyrotoxics over 90%.

Jaffe and Ottoman have presented an excellent report (*3*) on the use of tracer doses, usually 100 μc, as a diagnostic test for suspected hyperthyroidism. For this purpose, the usual basal metabolism test was only 67% accurate, and failed badly in certain classes of patients. Determination of blood iodine (I^{131}) was better—76% accurate; and the simplest test of all, thyroid uptake, was 91% accurate, with 5% of the remainder being placed by the observed data in a questionable group. They conclude, "We advise radioiodine uptake studies, when available, for all patients with clinically suspected hyperthyroidism, regardless of the type of treatment to be used."

For therapy of hyperthyroidism, larger amounts (3–5 mc) are needed which give an irradiation of some 15,000 equivalent roentgens (er) per gram of thyroid tissue. Clarke (*4*, *5*) at the University of Chicago lists recommendations for I^{131} over surgery as: (1) recurrent hyperthyroidism, (2) presence of other pathology making the patient a poor surgical risk, (3) propylthiouracil failures, (4) individuals over 45, and (5) people who want it.

Gordon and Albright (*6*) have reported on the first 120 cases treated at the University of Wisconsin; 24-hour

uptake was taken as a measure of potential success. Doses were purposely kept small (average 3 mc) on the theory that subsequent doses could readily be given as and if found necessary. Not one of the patients failed to respond, and one half were returned to normal thyroid status by a single dose. Three cases became hypothyroid but were readily controlled by thyroid administration. Contrary to some earlier reports, both nodular and diffuse goiters responded. They say, "We consider I^{131} the treatment of choice for toxic goiter, excepting only goiter during pregnancy, large goiters with mechanical obstructions, and hard glands involving danger of malignancy."

Feitelberg *et al.* of Mt. Sinai Hospital in New York have just published an equally encouraging report covering over 300 patients studied during a two-and-a-half year period (*7*). The average dose was 8.2 mc and the maximum 11. In the average patient, subjective improvement was noted in two to three weeks, and objective improvement in four to eight. Patients not well by then received a second dose; a few required a third. Radiation sickness was not observed. He says, "Because of the simplicity of the method, the absence of important complications, and the excellence of the results, it is our opinion that the use of internal radiation with I^{131} is the treatment of choice in diffuse toxic goiter."

Feitelberg also has proposed the charting of the supposed thyroid area by means of a directional tube. Used before and after partial thyroidectomy, it gives a reasonably clear picture of the part of the functional area still remaining and its present location (*8*). See Fig. 1. With improvements in counting methods, great strides in this direction can be anticipated (*9*).

Unfortunately, only 15–25% of thyroid tumors take up iodine in sufficient

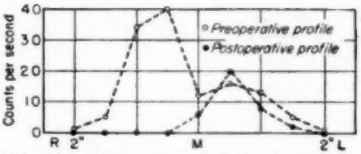


FIG. 1. This graph illustrates technique of plotting thyroid position with a directional counter (*8*)

quantity to be of value for radiation effects. This number may be increased by the use of suitable thyroid stimulants, by the removal of most of the "normal" thyroid, etc. Trunnell has suggested 40,000 er per gm of tissue or a total of 166 mc for a 100-gm cancer (45% excretion) (*10*). Even such doses (if properly distributed as divided doses of 30–50 mc) seem within the safe range. A number of successful cases have been recorded, and a number are now undergoing treatment with material being supplied by us under a special arrangement.

Seidlin *et al.*, in a progress report on the use of I^{131} therapy in carcinoma of the thyroid, speak of 12 treated patients. Of these, 7 were still living after 6 years, 3 were greatly improved, and 2 moderately improved. Total doses were large (200–1,000 mc), and no mention is made of serious side effects (*11*, *12*).

Blumgart *et al.* (*13*) have obtained favorable results in patients suffering from intractable angina pectoris by rendering them hypothyroid by means of moderate-to-large doses of I^{131}. They say that hypothyroidism induced by radioactive iodine promises to accomplish worth-while improvement through medical means without the inevitable risk and complications of surgical intervention.

Successful treatment of a metastatic lesion in the lung which had shown I^{131} uptake has recently been reported by Freedberg *et al.* (*14*).

Several excellent surveys covering

the therapeutic uses of iodine have recently been published (*15–31*).

The exact forms in which iodine exists during and after its thyroid uptake have been the subject of much study. Leblond and Gross, for instance, have used radioautography to show that at one hour the element is present mostly in the epithelium, at 24 hours it is in the "colloid" having passed through a "free" thyroglobulin stage (*32*). Taurog and Chaikoff (*33*) believe that the circulating hormone in the normal animal consists of thyroxine bound loosely to plasma protein. The influence of internal irradiation of the gland has been carefully studied (*34*).

The effect of halides, thiocyanates, and propylthiouracil upon the distribution and metabolism of radioiodine has recently been reported by Williams *et al.* with particular reference to clinical applications (*35*).

Goldberg and Chaikoff have shown that even doses of I^{131} as large as 300–800 μc produced no direct effect on the pituitary, even though the thyroid tissue remained atypical for many months (*36*). It was also demonstrated (*37*) that the parathyroid remained undamaged except for some fibrosis resulting from very high dosages.

The Mayo group under Watts (*38*) has studied lymphocytes from persons treated with I^{131} and do not find a significant change in the number or frequency of refractile granules therein.

Hertz (*39*) recently summarized the evidence for and against hazards to the patient from the use of I^{131}. The evidence seems to be overwhelming that the fears once held by some are rapidly being shown to be without foundation.

Very recently Hamilton and the California group found that the cyclotron-produced pure alpha emitter, astatine-211, causes the same type of thyroid tissue destruction (*40*). Since At^{211} radiation has a range only 1/40 that of the beta of iodine, there can be no effect on adjacent tissue, but the nature of its radiation and the short half-life (7.5 hr) contrive to make it of no therapeutic value at present.

While not of direct interest in medicine, reference may be made to a new method wherein short-lived free radicals (from organic reactions) are allowed to combine with I^{131}, and the resulting alkyl iodides, after dilution with carrier, are separated physically and assayed by counting (*41*).

2. Uses of Phosphorus-32

Phosphorus-32 is the element of second greatest medical interest. It is a pure beta emitter (1.69 Mev) of 14-day half-life. Abbott supplies it as a sterile, buffered solution of sodium phosphate with a small amount of carrier added.

After administration, P^{32} rapidly disappears from the blood and is taken up by certain tissues and cells. It is deposited in large amounts in bone and bone marrow, and in somewhat smaller quantities in the liver, spleen, and lymph nodes—hence its use in leukemia and polycythemia. The isotope is incorporated rapidly in both circulating erythrocytes and leukocytes; later the concentration in the erythrocytes decreases sharply, while that in the leukocytes goes down much more slowly (*42*).

A second characteristic is its incorporation in rapidly metabolizing tissues; thus neoplastic tissues take up amounts greater than normal, a fact which has been made use of in the localization of certain tumors, particularly those of the brain, where access may be had to the tumor area (*43*). Roswit, Sorrentino and Yalow have applied P^{32} to

the study of suspected malignancies of the testicles (*44*). Unfortunately, localization in bone tumors is not sufficient to achieve therapeutic results through irradiation.

However, Hertz has studied the effect of sodium acid phosphate, testosterone, and estrogens on the uptake of P^{32} by human metastatic cancer (*45*). Encouraging results were secured.

Since the pioneering work of Lawrence and associates at the University of California (*46*), P^{32} has been subjected to careful and extensive clinical trial and its place has been reasonably well established. As Karnofsky has emphasized (*47*), it has not proved consistently useful in Hodgkins disease and lymphosarcoma, and is without value in acute leukemia.

It is, on the other hand, the treatment of choice in polycythemia vera (*48*). It produces marked symptomatic relief, a remission in the abnormal hematological picture and a reduction in the size of an enlarged liver and spleen. It frequently restores the patient to a reasonably normal, useful life. In a recent report, the statement is made that this treatment is just as successful, and the prognosis for the patient just as favorable, as in the treatment of diabetes with insulin.

For intravenous administration, the usual single dose is 3–7 mc; this alone is said to produce satisfactory remission in 25% of patients. Hall and Watkins (*49*) believe that a second dose should not be given before an interim of eight weeks, after which second and third injections may be given provided the blood picture does not fall below certain stated standards.

The usual duration of remission after an effective single dose is 6–12 months. Groups at the Mayo Clinic and Washington University (*50*) found satisfactory remission in 85% and partial remission in the other 15% or 84 cases; 62% of these remissions lasted more than 6 months, 25% lasted more than 1 year, and 10% lasted more than 10 years. If the polycythemia vera reoccurs, remission can be induced a second time by more P^{32}. Whether P^{32} gives a longer survival period than X-ray or other experimental measures is difficult to say definitely. It seems significant to us that a summary of various reports showed 32 of 36 patients survived more than 5 years and 29 more than 10 years.

The chief advantages of P^{32} are: (1) the ease of administration, (2) the absence of radiation sickness and other toxicity, and (3) the simplicity with which the dose can be controlled. Its disadvantages are the possibility of bone marrow damage by overdosage, and the possible slightly greater incidence of acute leukemia.

The possibility of overdosage certainly would seem to be less important now that adequate and relatively simple assay procedures have been established. When P^{32} is given intravenously to normal persons, 10–25% is excreted in the first 7 days.

P^{32} has also been used in leukemia and allied diseases (*51–54*). See Fig. 2. Smaller doses are employed (5–7 mc) in order to have maximal depressant effects on leukopoiesis and minimal effect of the formation of erythrocytes and platelets. One Chicago group employs an initial dose of 5–7 mc and weekly sustaining doses of about 2.5 mc, as determined by excretion studies (*55*). This dosage has been found to give maximum therapeutic effect with a minimum of pronounced blood picture disturbance.

Oral rather than intravenous administration may be employed, in which instance at least 25% is lost in the stool and 75% may be assumed to be absorbed.

In chronic (but not acute myelogenous) leukemia, remission has been induced in a high proportion of patients;

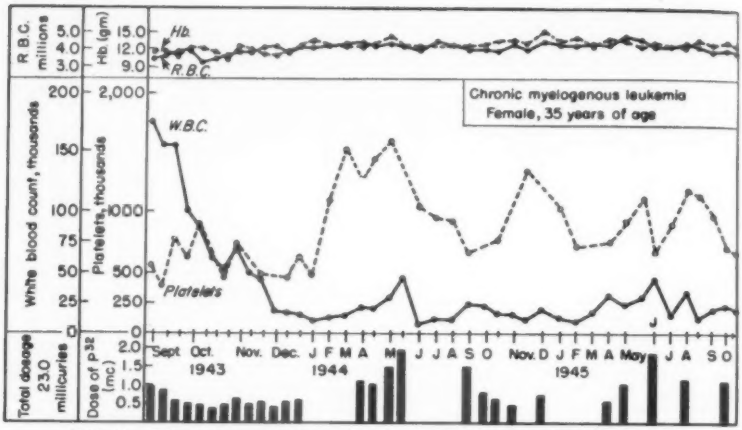


FIG. 2. Blood picture during phosphorus-32 treatment [Reinhard (*55*)]

reports indicate a duration of remission, and a prolongation of life at least equal to roentgen-ray therapy. For an excellent statement of the physiology of P^{32} use, see Friedell, Storaasli, and Marshak (*56*, *57*).

There have been several reports regarding multiple myeloma. The most recent is that of Lawrence and Wasserman (*58*), who used P^{32} in 11 cases, P^{32} and Sr^{89} in 9, and colloidal yttrium-90 in 1. Results were not markedly better than those from X-ray or stilbamidine. Combination therapy seems worthy of further trial. Stilbamidine-C^{14} does not localize sufficiently to indicate its use in therapy.

Low-Beer has pioneered the use of P^{32} absorbed on blotting paper of known dimensions and dried, for application directly to the skin. After preliminary experimental studies, he treated about 400 skin lesions including carcinoma, hyperkeratosis, warts, and hemangiomas. Over 90 % of the lesions disappeared (*59*).

The Friedell group in Chicago has employed P^{32} and its rate of deposition in a given extremity for determining the probable response of that patient to sympathectomy (*60*, *61*).

The use of P^{32} to label red blood cells to determine blood volumes is discussed in Section 4 of this article and its application in the localization of tumors in Section 3.

P^{32}-tagged leukocytes have been used in a study of the fate of white cells (*62*). The authors conclude that the process is more than a mere foreign body filtration by the reticuloendothelial system, as evidenced by the pronounced role played by the lungs.

To encourage the use of this isotope without removing necessary safeguards, the AEC, on page 3 of Supplement No. 3 (Feb., 1950) of their Isotopes Catalog and Price List No. 3, states that they will authorize the use of P^{32} by a physician in good standing provided that: (1) he has a suitable survey instrument, (2) he has been certified as qualified by a university medical school or hospital, and (3) his solutions be reassayed before use by the medical school or by a radioisotope supplier customarily engaged in making such measurements.

There is no need to recount here the many efforts that have been made to secure materials that would localize in tumor tissue to permit exploration or therapy.

Selverstone, Solomon and Sweet (*43*) recently reported on deposition of P^{32} in brain tumors. Since P^{32} is a beta emitter whose effective range in tissue is of the order of a few centimeters, it was necessary to devise a minature Geiger counter that could be inserted directly into the brain tissue. Good differentials between normal and pathologic areas were obtained and the method holds promise as a mechanical aid to the neurosurgeon. Localization of P^{32} has also been found in mammary and testicular tumors (*44*). The Selverstone group has also stated orally that the potassium (K^{42}) ion is similarly localized in brain lesions.

Most investigators have preferred to try more complex organic derivatives. Moore (*63*) of the University of Minnesota tried fluorescein in a wide variety of carcinomas and sarcomas, using as a criterion of uptake fluoresence under ultraviolet light. Less than half of abdominal tumors gave satisfactory uptake but, in lesions of the central nervous system, accuracy in both a positive and negative sense was of the order of 90%. He then incorporated iodine into this molecule and it was at this point that active cooperation with Abbott Laboratories was begun. I^{131} has the advantage over P^{32} in that it permits measurements to be made outside the skull and thus quite independent of operation procedures. The diiodo derivative proved less toxic than the tetraiodo and has since been used exclusively (*64*).

The factor of concentration is only moderate—some eight to ten fold in favorable cases. The mass of the tumor is small in comparison with the immediately adjacent normal tissue. Geiger tubes are neither particularly directional nor gamma-sensitive; even at best, readings represent the summation of the tumor and those portions of the brain beyond it. Greater directional effect can be secured by the use of a narrow opening in a heavy lead shield, but the counts are thereby so decreased that the time necessary to record a statistically significant number of counts exceeds the time which may be devoted to any given location, and there is actually danger of overlooking tumors—due to small variations in positioning of the counter tube.

We early found that the dye made by the original method was a mixture and contained a small amount of labile halogen. We have devised a new preparation yielding what appears to be essentially pure diiodo-I^{131}-fluorescein. This material has been used by practically all investigators during the past year. The LD-50 in mice is greater than 250 mg/kg; the sodium salt is contained in a solution of *p*H 7, and has no labile iodine.

The concentration of activity in the thyroid following administration is less than that from the customary and perfectly harmless tracer dose of iodine. Excretion is through the urine and feces, and the compound's biological life is 2–3 days.

Localization in the tumor seems to proceed more rapidly than with the original dye, possibly due to the absence of the preferentially absorbed fluorescein. Specific activity does not seem to be critical, but we have found a convenient value to be from 10–15 mc per gm of dye.

Recently Davis, Martin, Ashkenazy, LeRoy, and Fields reported before the American Neurological Society more

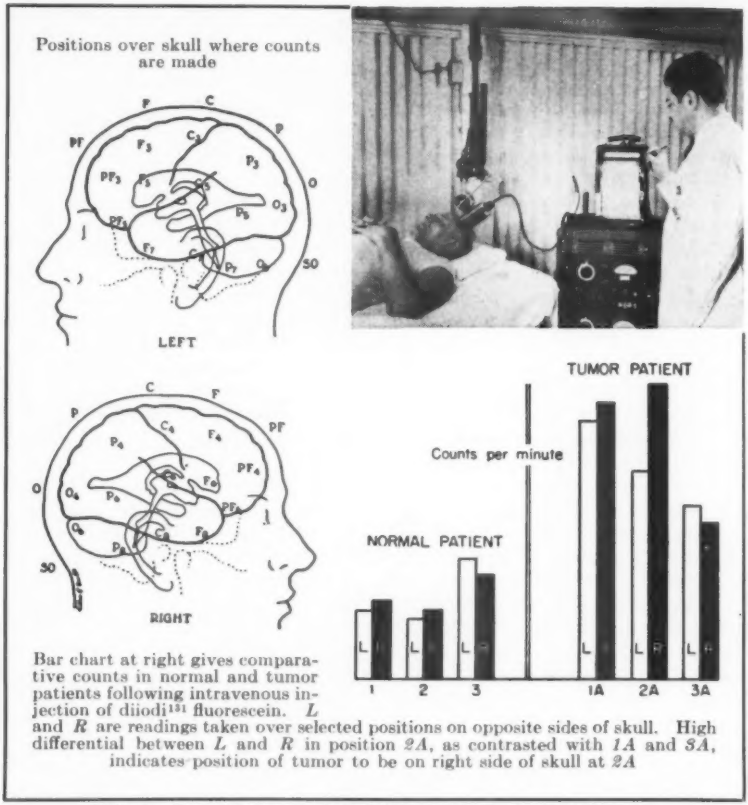

Positions over skull where counts are made
LEFT
RIGHT
TUMOR PATIENT
Counts per minute
NORMAL PATIENT
L R
1 2 3 1A 2A 3A
Bar chart at right gives comparative counts in normal and tumor patients following intravenous injection of diiodi^{131} fluorescein. L and R are readings taken over selected positions on opposite sides of skull. High differential between L and R in position 2A, as contrasted with 1A and 3A, indicates position of tumor to be on right side of skull at 2A

FIG. 3. Use of I^{131}-tagged diiodofluorescein for tumor diagnosis

than 200 consecutive cases thus localized with an accuracy of 94–95%. See preliminary report (*65*). (Work at Hines Veterans Administration Hospital and at Northwestern University since then has raised the total to over 350.) The formal paper is to appear shortly in the *Journal of the American Medical Association.*

Their method which has been adopted in principle by most other users is briefly as follows: A solution containing 1 to 1.2 mc of I^{131} activity (about 1 cm^3) is given intravenously. "Counts" from the brain area become significant within 15–30 minutes, and are most pertinent from then on up to 1½–2 hours. Probably due to general edema, the actual concentration in a diseased brain usually is higher than in a normal brain and it approaches 1000–1200 cpm measured externally (1-inch tube opening). See Fig. 3. At or just before this time, measurements are made at some 32 predetermined locations around the skull. Corresponding areas on opposite sides are measured next to each other and compared. The differ-

ential between such corresponding areas, one normal, and one containing a tumor, will be 80–200 cpm. Differentials of less than 50 cpm are of doubtful significance. During the next hour or so, all values decline gradually, but in most instances a differential persists.

Since differences in technique and equipment may cause significant variations, it is essential that each group run a number of "normal" cases to establish the "normal" counts for the various positions about the skull. Marked variations from these are, of themselves, of primary diagnostic value in establishing the existence of physiologic abnormality. The use of fewer positions for counting is likewise to be avoided; in fact, suspected areas must be rechecked several times during the observation. Such care not only befits the serious nature of the lesion being studied, but has occasionally brought to light unsuspected multiple tumors. Obviously, with mid-line tumors, comparison of opposite sides does not suffice and one must rely on an accurate "mapping" of the suspected areas.

The Davis group states that the position and size of the tumor can be quite definitely defined and an estimate made of its malignancy. In their work, such accuracy and success is possible because the isotopologist and neurosurgeon work together during each individual test; they can thus recheck suggestive values before concentration changes have taken place; the same team is present during the operation, and has the opportunity to recheck the examination on the patient after operation, and again if recurrence or incomplete removal is suspected.

Thoma, using a similar procedure, has reported favorably on some 60 cases of brain tumors, 20 of which have been verified (*66*).

Tumors of the upper spinal cord have been similarly located by the Davis group, but with difficulty because of the stray radiation from the liver.

LeRoy, Tweedy, and Ashkenazy have submitted a paper to the *Journal of Laboratory and Clinical Medicine* concerning the health physics aspects of the use of diiodo-I^{131}-fluorescein for diagnostic studies. They conclude that in doses of 1000–1100 μc given intravenously, it can be used safely for diagnostic purposes. They believe there is no significant radiation hazard to the patient or to the institution. While there is a potential radiation hazard in the case of attendants of incontinent patients, in practice, significant contamination has not been observed (*67*).

This, then, it would seem, is a very useful, accurate, convenient, and painless diagnostic test—one which will grow in value as increasingly sensitive detection equipment becomes available.

Myers (*68*) has diazotized and coupled sulfanilic acid and 2,6-diiodosulfanilic acids with varied intermediates to form both acidic and basic dyes. In all, some 70 compounds were tested on four different tumors growing in mice. There was definite localization, as compared with blood levels, in some 18 members of the series.

Gallium, a bone-seeking element, has been extensively studied by Dudley *et al.* at the Naval Research Hospital. It is unquestionably taken up by bone tumors, but the diagnostic and therapeutic possibilities remain to be evaluated (*69–72*).

4. Other Diagnostic Agents

The clinical importance of determining blood volumes accurately is becoming well recognized. The azo dye T1824 (Evans Blue) has been extensively studied, but has several obvious disadvantages, notably that repeated

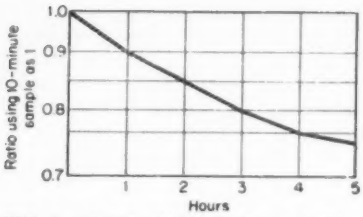


FIG. 4. Graph of iodinated serum albumin disappearance from the blood (*84*)

determinations cannot be made in the same individual over a short period of time.

By means of radioisotopes, easier and more accurate methods have been evolved. In 1941, P. Hahn *et al.* described a method for determining red-cell volume by means of radioactive-iron-tagged red cells (*73*). They found that the iron, given orally to dogs, became incorporated in their erythrocytes and that the tag remained as long as the cell existed intact. Almost simultaneously L. Hahn and Hevesy obtained P^{32}-tagged red cells by orally injecting this isotope into a rabbit, and Hevesy found that incubation of the cells in a test tube accomplished the same purpose (*74, 75*). Nylin used this as a method of studying blood volumes (*76*). Since that time numerous papers describing modifications of the method have appeared (*77–80*).

Based upon the original observations of Fine and Seligman (*81, 82*), Krieger, Storaasli, Friedell *et al.* (*83*) have proposed a method involving I^{131}-tagged human serum albumin. Being derived from a constituent of plasma by methods which do not appreciably alter its properties, the tagged serum would seem to satisfy all biological requirements for such a diagnostic reagent.

The procedure is indeed simple, no incubation being required. An amount of the tagged albumin, sterile, in standardized solution (as supplied by Abbott) corresponding to 30–50 μc, is diluted to 20 cm^3 with saline. An aliquot is reserved for dilution with serum to serve as a standard. The remainder is given intravenously, and a sample, or samples, is withdrawn from the opposite area between 10 and 30 minutes later. The sample is centrifuged (15-30 minutes) and the activity of 1–2 cm^3 of the plasma determined by the usual Geiger counter methods or by a gamma ionization chamber. Either liquid counting, or evaporation, (as in NaI^{131} assays) may be used. From this value and the hematocrit, blood volume can be calculated as follows: (*Counts Std.* × *Vol. Injected* × *Dil. of Std.*) ÷ (*Counts in Sample/cm³*) = *Plasma Protein; Plasma Volume* ÷ (100 − *Hematocrit*) = *Blood Volume.*

Storaasli, Krieger, *et al.* compared the three methods carefully on ten dogs. They state, "The iodinated protein method permitted accurate determinations of plasma volumes for a much longer period after injection than did the other two methods. It was simple and direct. It permitted the calculations of the volume within a few minutes after samples were obtained. It appeared to have a decided advantage over blood volume estimation with P^{32}-tagged red cells and the T1824 dye method."

The same group has reported (*84*) on extending the work to 76 human subjects, in 15 of whom a direct comparison was made with the T1824 method. It was found that at the end of one hour more than 90% of the injected tagged protein was still present in the blood; some 78% remained at the end of four hours. (See Fig. 4; this curve is quite characteristic within ±5%).

Some of the tagged protein that is removed finds its way into the lymph; 8% to 12% of the activity is found in the urine in 24 hours (*85*). Some finds its way to the thyroid, but in

mice, at least, this did not exceed 5% of the injected dose. The latter effect is, of course, quite insignificant and can readily be prevented by the administration of inactive iodide.

Crispell, Porter, and Nieset have reported using an essentially similar material but only in the amount of 12 μc per determination (*86*). By withdrawing a blood sample just before injecting a new dose, they found that the amount remaining in the blood at that time could be accurately determined; this enabled them to make repeated determinations on the same patient. Repeated serial determinations in the same patients gave values which checked within 2%. Combining the iodo plasma albumin and the P^{32}-tagged red cells method, enables one to make a *direct* measurement of total blood volumes.

Optimal time for the taking of samples seemed to be at 10–25 minutes. Surface radiation over the thyroid and liver areas ranged from 0.01 to 0.15 mr, and had practically disappeared after 24 hours. They found up to 60% of the iodide to appear in the urine during 24 hours. Krieger *et al.* found that some of the tagged human serum albumin is found in the lymph (of dogs), the amount at the end of 10 minutes being negligible but increasing moderately over the 12 minutes of their observation (*85*).

There are other pertinent references regarding the use of tagged blood constituents (*87–89*).

Gray and Sterling have reported on the Cr^{51}-tagging of red cells for red cell volume determinations on dogs (*90*). When 7–26 μc of tagged dichromate were allowed to stand with 50 cm^3 of heparinized blood, practically all became attached to the cells and only 1% remained in the plasma. After reinjection of the red cells, samples were removed as usual, dried over night, ground and counted on planchets. Corrections were applied to offset the softness of the X-rays self-absorption. The advantage of the method is the tightness of the bonding, no chromium being lost from the cells during the first-day post injection; the loss at three days was only 15%.

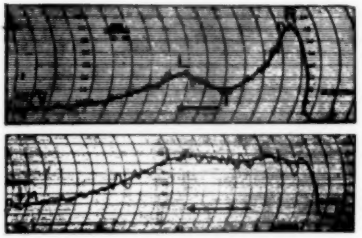


FIG. 5. Radiocardiography (*94*)

Somewhat older, dating back to 1942, is the use of Na^{24} for determining circulation time. In the method of Smith and Quimby, 60–200 μc of $Na^{24}Cl$ were injected at any predetermined site, and the time necessary for the appearance of activity at the sole of the foot was noted (*91*). The arm-to-foot circulation time varied from 15–90 seconds, with normals coming in the 45–55-second range. More interesting clinically was the build-up of counts in any remote area. For instance scleroderma and Raynaud's disease uniformly gave curves falling below normal. Kety and Cooper have proposed the "sodium clearance constant," a measure of local circulation, as a clinically useful determination (*92, 93*).

During the past year, Prinzmetal has developed a modification known as "radiocardiography" (*94*). A well-shielded, directional, gamma-sensitive tube is placed directly over the heart of the patient, and 40–300 μc of Na^{24} are given intravenously, as rapidly as possible. In Fig. 5, the peak *R* in the curve drawn by the output of the Geiger tube represents the flow of the still relatively concentrated "slug" of activity through the *right* side of the

heart. About 5–6 seconds later, a second peak *L* appears which is the flow through the *left* chamber of the heart. Because of intermediate dilution, this is obviously not as sharp or as high. If either side of the heart has lost some of its pumping power, there is a greatly increased passage time, and even fusion as in the lower radiocardiograph in Fig. 5. Thyrotoxicosis shows up as a more rapid circulation.

A formidable disadvantage is the 14.8-hour half-life of Na^{24}, but in spite of this, Prinzmetal reported on 400 cases in which it was used to differentiate heart disease from conditions simulating cardiac insufficiency, and we understand this program is continuing.

Forbes and Perley (*95*) have determined the total body content of sodium, and found the normal adult value to be 41–43 milliequivalents per kg body weight, with higher values being found in young children. The method has been applied by the British to the venous flow during labor (*96*). Levitt and Gandino (*97*) have made simultaneous use of Na^{24}, K^{42}, and D_2O along with inulin excretion to determine the average intracellular cation concentration. The value reported was 115 milliequivalents per liter for K and 35 for Na.

Layton and Frankel (*98*) have attempted to diagnose cartilagenous tumors by treatment with a nutrient solution containing S^{35}-tagged sodium sulfate. They conclude that in adult human tissues there is a differential fixation, which may be used as a rapid confirmatory test.

The use of S^{35}-tagged methionine will be discussed in Part II, Section 7, to be published next month.

5. Tumor Therapy

Prior to some ten years ago, the administration of radiation to a given tissue was largely of interest to the physicist, the source of irradiation being X-rays from radium or one of its daughter elements. Today, the problem is becoming a chemical one. Which of the some 750 known chemical isotopes best supplies the radiation (alpha, beta, or gamma) required with a minimum of side effects and danger? How may that isotope be most effectively induced to localize so as to yield the desired therapeutic effects?*

The range of X-rays or gamma rays is measured in feet so that it is physically impossible to localize their effects entirely in any given area. The alpha particle, on the other hand, has a range in tissue of fractions of a millimeter and 100% dissipation of energy is secured solely at the site of deposition. Alpha emitters are found primarily among the toxic bone-seeking metals like radium and plutonium and therefore have no practical value. A reasonable compromise is a beta emitter whose particles have a mean free path of from one millimeter to a centimeter or two. This constitutes a complete reversal of technique because, to avoid the necrosis from single sources of radium or radon (needles), the radiologist has purposely screened out these betas and depended upon the much less efficient gamma. Actually, even though it is not used for therapeutic purposes, a gamma component is sometimes convenient in that it permits following the localization or measurement from outside the body, as we saw in the case of iodine.

If the isotope is to be used in medicine, it must also meet these additional exacting requirements: (*A*) It must be

* For organ dosage determinations in the use of radioactive isotopes, see the very excellent article of Marinelli (*99*).

TABLE 1

Therapeutically Useful Isotopes

Isotope	*Half-life*	*Beta*	*Gamma*	*For*
Na^{24}	14.8 hr	1.39	2.75	Total body irradiation
P^{32}	14.3 d	1.71	....	Treatment of leukemia
K^{42}	12.4 hr	3.6	1.5	Total body irradiation
I^{131}	8.0 d	0.60	0.37	Thyroid studies
Br^{82}	34.0 hr	0.46	1.3	Brominated dyes
Au^{198}	2.7 d	0.97	0.44	Tumor injections

nontoxic in the doses required, and be free from toxic impurities or daughter elements. (*B*) It must not localize strongly in areas other than those to be treated. (*C*) It must have a short half-life so that radiation will not persist beyond the desired period. The same result is achieved if its biological half-life (the period it remains in the body) is brief. (*D*) On the other hand, its half-life must be sufficient to permit conversion to useful forms and must outlast transportation time to the site of administration. The maximum desirable half-life may be taken as 10–15 days and the workable minimum 12 hours. (*E*) It must be capable of intensive and economical preparation if it is to achieve therapeutic usefulness. Today that means production in a nuclear reactor.

Hahn, Sheppard, *et al.* recently reviewed 450 different isotopes and came to the conclusion that only 5 meet the highest standard of requirements (*100*). If one is willing to make certain allowances, this number can be increased to 22. At first quite startling, but nevertheless preponderately accurate, is their statement that had radium been discovered recently and evaluated in the light of the above requirements, it would never have been used in the treatment of a single tumor.

Table 1 shows some of the more eligible isotopes. In addition, Mn^{52}, Cu^{64}, Zn^{72}, As^{76}, Kr^{91}, Sr^{91}, Y^{90}, Ag^{106}, Ag^{111}, Cd^{115}, Sn^{121}, Sb^{121}, Sb^{127}, Xe^{133}, W^{187}, and Bi^{206} offer good possibilities when their biological properties are better understood.

The University of California group has done much pioneering on the distribution of particulate colloids, initially chromic phosphate (*101*), and more recently on the distribution of solutions of zirconium, columbium, and yttrium (*102–104*). They have shown that the biological distribution depends upon the nature of the particles. Zirconium particles of relatively large size show rapid disappearance from the blood stream (half-life, ½ minute) and are deposited primarily in the liver and spleen. Colloids of intermediate particle size disappear more slowly (20-80 minutes) and are deposited primarily in the bone marrow and spleen. Once deposited, no significant distribution takes place over a 2–4 weeks period, and body excretion is slow.

In an effort to make use of the favorable radiation characteristics of P^{32}, Allen *et al.* tried injecting sodium phosphate directly into mouse adenocarcinoma (*105*). The material was rapidly absorbed, and there was no tumor regression. Insoluble chromic phos-

phate, of particle size about 1 micron, was therefore tried and, for technical reasons, injections were best made into tissues surrounding the tumor. Lesions smaller than 2 cm in size responded best (as would be expected from the 0.7-cm range of the 1.7-Mev betas) and showed permanent regression. Animals with larger tumors died from associated toxemia. In other areas, except in the atrophied regional lymph nodes, only traces of P^{32} were found.

Regressions were noted in other types of tumors as well, but melanosarcoma and fibrosarcoma required much larger amounts of radiation. There was no microscopic evidence of distant parenchymatous damage.

To Hahn and his group must go much of the credit for the intensive clinical application of radiocolloids (*106*). They established that colloidal ferric hydroxide, given by vein, was distributed in the reticulo-endothelial system roughly in proportion to the phagocytic activity, with maximum concentration in the spleen. Manganese dioxide did not deposit in the spleen, the manganese tending to accumulate in the pancreas, possibly following liberation in an ionic form.

With the advent of the nuclear reactor, the economics of isotope therapy became important. In the reactor, Au^{197} has an unusually high neutron-capture efficiency (100 barns, as compared with 0.01 barns for sulfur) and is converted by an (n,γ) reaction to Au^{198} with a half-life of 2.7 days. The latter means not only that 10–12 days of pile irradiation suffices for the production of maximum activity, but that for all practical purposes its effect in the body is gone after 2–3 weeks.

For over two years, we have been able to work with Hahn and supply gold colloid to him. The service Abbott Laboratories renders in connection with this gold colloid is typical of the service this company can render hospitals and other institutions that do not have "hot" labs and are otherwise unequipped to handle very-high-activity samples.

We have irradiations carried out both at Oak Ridge and in the reactor at Argonne National Laboratory. Argonne is about 1½ hours' travel time from our laboratories. The freshly withdrawn samples, when they are returned to us, are heavily shielded and contain up to 750 mc of gold activity, an activity certainly not to be tolerated in an ordinary hospital laboratory (250 mc gives maximum permissible exposure of 10 mr at 6–7 feet from the sample). By the time our processing is completed and shipments are made some 20 hours later, about 250 mc of activity remain. This activity can be shielded in a 30-lb lead "pot" which is much more adaptable to shipment by air than would be the much heavier shielding required around samples freshly withdrawn from the reactor.

We have made extensive studies of the method of colloid production originally suggested by Hahn, that is, reduction of $AuCl_3$ in alkaline solution by ascorbic acid in the presence of gelatin. As a result, our colloid is heat sterilized, sterile, pyrogen free, stable to 10% NaCl solution, to pectin, and other colloids. Electron microscope measurements indicate surprisingly uniform particle size (0.001–0.003 micron) with only a few larger particles. Activities of 15–20 mc/cm^3 or more are readily produced and can be increased to 25–30 when desired.

Goldie and Hahn (*107*) have studied the effects of two radioisotopes, Au^{198} and I^{131}, on sarcoma-37 cells growing vigorously in the peritoneal fluid of mice. Doses were small (of the order of 0.2 to 0.4 mc). With I^{131}, evidence of damage to the tumor cells was detected largely by their inability to grow when injected into other animals. With higher dosages, actual disintegra-

tion of the tumor cells was noted. Even this is quite surprising since the readily diffusible iodide had completely disappeared after 24–48 hours.

With colloidal Au^{198}, on the other hand, (given 2 to 5 days after inoculation) tests on three consecutive days after treatment showed the absence of tumor cells. In controls, tumor cells were numerous and showed high proportion of mitoses. Again nonviability of the altered cells was demonstrated by their inability to multiply or even to survive after their transfer to new mice.

On injection, the ultramicroscopic colloidal gold particles mixed freely with the peritoneal fluid. Later they condensed into dot-like particles in the cytoplasm of the macrophages. The macrophages containing the gold maintained their structural and functional integrity, while lymphocytes and polymorphonuclears are partially and temporarily destroyed by the radiation effect.

The conclusion is drawn that the sarcoma-37 tumor cells are highly sensitive to small amounts of radiation well tolerated by the mice themselves while macrophages showed very high resistance. Thus the complete destruction of free tumor cells in the peritoneal cavity may be described as a selective radiotherapeutic effect of the radioactive colloidal gold.

Hahn's clinical work has been about equally divided between the treatment of lymphoid-microphagic diseases and tumor therapy by direct infiltration (*108*). His group has used some 15,000 mc (the equivalent of 15 gm of radium) in giving 620 treatments to 268 patients.

The method of direct infiltration of the tissue to be irradiated represents a considerable "come-down" from the theoretical ideal of selective localization following intravenous administration. To us as chemists, however, it represents a more realistic view of the current situation. The more we use isotopic tracers, the more convinced we become of the complexity of biological processes and the fact that at least some of almost everything thus administered becomes dispersed throughout the body. To subject "innocent" normal tissues to the radiation attendant upon the localization of this range of activities is almost out of the question.

This point becomes increasingly important as evidence increases that we may have to revise our ideas of the amount of isotopic radiation required to destroy tumor cells completely. Clinically, doses of 50–150 mc are common. The optimal amount appears to be of the order of 0.6 mc of gold per gram of tissue.

Hahn has recently gone as high as 200,000 er, in which range the contribution of the gamma rays plays a significant part in the radiation of the regional lymphatics (*108*). Obviously, the time over which the dose is acting is important, and 1 roentgen given over a week or so is less lethal than the same energy given over a few minutes. On the other side of the ledger, there seems little question but that avoidance of injury to adjacent tissue will permit much larger doses with no reduction in safety.

The question is often asked why, if the tumor can be reached for injection, surgery is not performed. The oncologist and the surgeon frequently find tumors where extensive scar tissue or the condition of the patient preclude operative procedures or the use of X-ray. Then, too, if a tumor has been removed, stray cells may remain that travel along lymph channels and start new tumors. The implantation in the operative area of a radioactive material which will help to destroy these cells before they become established, is the goal toward which several collaborating groups are working, with,

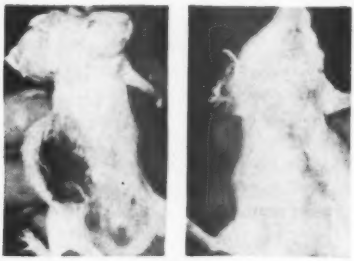


FIG. 6. (Left) Untreated control mouse with two large transplanted sarcomas. (Right) Same mouse with depilitated scars that remained after complete regression of treated tumors

it seems, a reasonable chance of success.

The second big question is how well does such a colloid remain in the tumor. Again animal experimentation, as well as clinical trial, is supplying the answer. See Fig. 6.

Recently, Williams of the Medical College of Virginia reported before the Southern Medical Association the results of his studies (*109*). Using a semipermeable cellophane bag, he found not more than 4% of the gold as we supplied it dialyzes over several days. Mice and rats readily tolerated 3 and 7 cm^3 of an equivalent "gold" colloid, showing absence of "gold" toxicity. Following intraperitoneal, intracardiac, intrasplenic, and intratumoral injections, the loss of radiogold through the urine and stools was less than 0.1% during the first week, and none thereafter. In other words, 99% of the active gold is retained within the tissue indefinitely.

Four types of mass tumors (usually 1–1.5 cm in diameter) were injected with small doses of colloid. With 22 relatively solid carcinomas, 15 retained 95–100%, 5 retained 90–95% and 2 retained 85–90%.

Injection of 200–500 μc of colloid into sarcomas-180 and 37 gave regressions in 21 of 31 tumors—67%. Local infiltration and systematic administration of nitrogen mustards gave 42% regression; combination of the two gave 82% regression.

Another recent report is that of Sherman *et al.* of Washington University, St. Louis (*110*). They have taken the colloid we supplied and added pectin as a further suspending agent. Using interstitial injections, transplanted squamous-cell carcinoma in mice could be safely and completely "cured" by 200–300 μc per cm^3 of tumor tissue, with high survival rates. Injected into the paracervical tissue of rabbits, gold entered the lymphatic system and reached primary and secondary lymph nodes where definite radiation effects were noted. Introduced into the uterine horns of rabbits, radiation effects extended to the ovaries.

Sherman has also reported on the use of colloidal gold in the treatment of cervical cancer. The doses were purposely held below the presumed optimal therapeutic level so that possible toxic effects could be evaluated. None were found, and it was possible to demonstrate active uptake and transport along lymphatic channels. It may, therefore, offer a valuable adjunct to surgical removal, by decreasing the possibility of the development of metastases (*111*).

Clarke and LeRoy likewise have reported that colloidal gold injected into tissues remains fixed at the site of injection (*112*). A 50,000-er dose has been found effective without harmful local or systemic reactions. When the gold is given intravenously, some 80% goes to the liver.

We have recently received a personal report from Dr. J. H. Müller of Zurich. In spite of the difficulties of transatlantic transportation he has used our gold colloid in 6 cases of inoperable ovarian malignancies. Administration was by intraperitoneal injection of 100–150 mc, the patient being mechanically rotated at frequent intervals.

The results have been in his words "decidedly positive," notably in the stoppage of ascitic fluid production. No apparent damage has resulted to surrounding tissues. There was only nominal excretion of activity in the urine; no side reactions were noted.

It is to be emphasized that there is every advantage in removing all large tumor masses. Several gold treatments are commonly employed, but the management of each case is an individual problem, and no fixed rules can be laid down. We have recently made a number of shipments to Latin American countries for use on tumors.

Dr. D. W. Smithers of London reported upon his experiences with gold before the recent International Congress on Radiology. The abstract of his paper is in part as follows: "Intraperitoneal injections of colloidal gold were given to five patients, once shortly before death so as to observe its distribution and four times as treatment for carcinomatosis peritoneii. One of these patients, a woman of 41, was treated with a radical mastectomy for carcinoma of the breast in January, 1947. She remained well until January of this year when she had a rapid onset of abdominal swelling and was found to have ascites and an ovarian tumor; the whole peritoneal surface was studded with secondaries. Both ovaries were removed and an intraperitoneal injection of 95.5 millicuries of colloidal gold-198 in 1000 cm^3 of saline was given shortly afterwards. She had some flatulence and discomfort after food for a few weeks but has otherwise remained very well for six months since her treatment, had no return of ascites. She and the three others since treated are being followed with interest. Dr. Müller of Zurich has been using a similar technique and is reading a paper on this subject to the congress this week. We have measured the gamma-ray dose received by an ionization chamber swallowed before treatment and passing through the intestine during the period of activity of the gold. This has proved to be an interesting observation, the physics department having predicted the gamma-ray dose that would be measured with remarkable accuracy."

Müller pioneered the use of Zn^{65}; this element in pectin has a remarkable affinity for the pulmonary capillaries, as much as 40 mc having been given to a single patient with no activity demonstrable in the urine (*113*).

Müller has also employed simple solutions of Co^{60} salts (and enough NaI to render them radio-opaque) in flexible "balloons" for the irradiation of bladder tumors (*114*). An English group, Wallace, Walton and Sinclair (*115*), has used Na^{24} for irradiation of the bladder in carcinoma; 200 mc in 150 cm^3 of Na^{24} solution were used to give gamma-ray doses of 2,000–3,000 r. All of the ten cases showed some evidence of regression.

Haik has discussed the advantages of a pure beta emitter in the treatment of ophthalmological lesions (*116*).

Since arsenic has long played an important role in medicinal chemistry, it seems quite appropriate to mention the work of Jacobson and his group at the University of Chicago on As^{76} as a source of both radiation and chemotherapeutic effects. Cacodylic acid was pile-bombarded and the As isolated as the trichloride (*117*). Patients treated included 24 with tumors, 2 with polycythemia, and 1 with metastatic carcinoma. They concluded that in view of the considerable difficulties in handling, this isotope offered no particular advantages (*118, 119*).

A theoretically interesting modification is to localize an element like U^{235} in an organ such as the liver or spleen, and then to subject the area to slow neutron bombardment. The nuclear disintegration thus induced produces

greater radiation effects than beta radiation itself due to the fission recoils (*120*).

Radioactive colloidal gold has been shown to produce uniform and consistent remissions in chronic leukemia in humans, both in the lymphogenous and myelogenous forms. In these types it sometimes possesses the advantage of longer term palliation (*121*).

The group at the Southern Research Institute have shown that administration of C^{14}-labeled $NaHCO_3$, and C^{14}-labeled 2,6-diaminopurine have no effect on the pattern of deaths from leukemia in mice (*122*).

The many experiments enumerated above certainly indicate the potential value of individual radioisotopes in the radiation therapy of tumors.

BIBLIOGRAPHY

1. K. Bernhard, *Bull. Schweiz. Akad. Med. Wiss.* **5,** 331 (1949)
2. P. C. Aebersold, *J. Clin. Invest.* **28,** 1247 (1949)
3. H. L. Jaffe, R. E. Ottoman, *J. Am. Med. Assoc.* **143,** 515 (1950)
4. Am. Med. Assoc. Meeting, San Francisco, June 26–30, 1950
5. T. H. Clarke, Natl. Goiter Assoc. program (1950)
6. E. S. Gordon, E. C. Albright, *J. Am. Med. Assoc.* **143,** 1129 (1950)
7. S. Feitelberg *et al.*, *Arch. Internal Med.* **85,** 471 (1950)
8. S. Feitelberg *et al.*, *Am. J. Med. Sci.* **216,** 129 (1948)
9. B. M. Dobyns, B. Skanse, F. Maloof, *J. Clin. Endocrinol.* **9,** 1171 (1949)
10. J. B. Trunnell, *Trans. N. Y. Acad. Sci.* **11,** 195 (1949)
11. J. M. Seidlin *et al.*, *J. Clin. Endocrinol.* **9,** 1122 (1949)
12. J. B. Trunnell *et al.*, *J. Clin. Endocrinol.* **9,** 1138 (1949)
13. H. L. Blumgart, *et al.*, *Trans. Assoc. Am. Physicians* **62,** 162 (1949)
14. A. S. Freedberg, *et al.*, *J. Am. Med. Assoc.* **144,** 16 (1950)
15. M. S. Raben, E. B. Astwood, *J. Clin. Invest.* **28,** 1347 (1949)
16. M. M. Stanley, *J. Clin. Endocrinol.* **9,** 941 (1949)
17. W. H. Biehrwaltes *et al.*, *Univ. Mich. Med. Bull.* **16,** 2 (1950)
18. J. C. Werner, E. H. Quimby, C. Schmidt, *Am. J. Med.* **7,** 731 (1949)
19. F. R. Keating, Jr., *et al. J. Clin. Invest.* **28,** 217 (1949)
20. R. H. Williams, *J. Am. Med. Assoc.* 139, 1064 (1949)
21. M. H. Soley, N. Foreman, *J. Clin. Invest.* **28,** 1367 (1949)
22. R. W. Rawson, *J. Clin. Invest.* **28,** 1330 (1949)
23. D. E. Clark, R. H. Moe, E. E. Adams, *Surgery* **26,** 331 (1949)
24. M. H. Soley, E. R. Miller, N. Foreman, *J. Clin. Endocrinol.* **9,** 29 (1949)
25. M. P. Kelsey, S. F. Haines, F. R. Keating, Jr., *Postgrad. Med.* **6,** 263 (1949)
26. M. P. Kelsey, S. F. Haines, F. R. Keating, Jr., *J. Clin. Endocrinol.* **9,** 171 (1949)
27. A. M. Potts *et al.*, *J. Lab. Clin. Med.* 34, 1520 (1948)
28. M. Prinzmetal *et al.*, *J. Am. Med. Assoc.* **140,** 1082 (1949)
29. I. S. Ravdin, E. Rose, J. D. Maxwell, *J. Am. Med. Assoc.* **140,** 141 (1949)
30. D. S. Childs, Jr., F. R. Keating, Jr., J. E. Rall, *J. Clin. Invest.* **29,** 726 (1950)
31. J. Berkson *et al.*, *J. Applied Physiol.* **2,** 522 (1950)
32. C. P. Leblond, J. Gross, *Endocrinology* **43,** 306 (1948)
33. A. Taurog, I. L. Chaikoff, *J. Biol. Chem.* **176,** 639 (1948)
34. D. D. Feller *et al.*, *Endocrinology* **45,** 464 (1949)
35. R. H. Williams, H. Jaffe, J. A. Taylor, *Am. J. Med. Sci.* **219,** 7 (1950)
36. R. C. Goldberg, I. L. Chaikoff, *Endocrinology* **46,** 91 (1950)
37. R. C. Goldberg *et al.*, *Endocrinology* **46,** 72 (1950)
38. W. E. Watts, D. M. Mathieson, *J. Lab Clin. Med.* **35,** 885 (1950)
39. S. Hertz, *New Orleans Med. Surg. J.* **103,** 51 (1950)
40. J. G. Hamilton *et al.*, *Proc. Soc. Exptl. Biol. Med.* **73,** 51 (1950)
41. R. W. Durham, G. R. Martin, H. C. Sutton, *Nature* **164,** 1052 (1949)
42. L. A. Erf, L. W. Tuttle, *Am. J. Med. Sci.* **203,** 83 (1942)
43. B. Selverstone, A. K. Solomon, W. H. Sweet, *J. Am. Med. Assoc.* **140,** 277 (1949)
44. B. Roswit, J. Sorrentino, R. Yalow, *J. Urol.* **63,** 724 (1950)
45. S. Hertz, *J. Clin. Invest.* **29,** 821 (1950)
46. J. H. Lawrence, K. G. Scott, L. W. Tuttle, *Internatl. Clinics* **3,** 33 (1939)
47. D. A. Karnofsky, *New England J. Med.* **239,** 299 (1948)
48. J. H. Lawrence, *J. Am. Med. Assoc.* **141,** 13 (1949)
49. B. E. Hall, C. H. Watkins, *Am. J. Med. Sci.* **213,** 621 (1947)
50. L. A. Hempelmann, Jr., *et al.*, *J. Lab. Clin. Med.* **29,** 1021 (1944)
51. B. V. A. Low-Beer, J. H. Lawrence, R. S. Stone, *Radiology* **39,** 573 (1942)
52. C. A. Doan *et al.*, *J. Lab. Clin. Med.* **32,** 943 (1947)
53. J. H. Lawrence *et al.*, *J. Am. Med. Assoc.* **136,** 672 (1948)
54. J. H. Lawrence, B. V. A. Low-Beer, J. W. J. Carpenter, *J. Am. Med. Assoc.* **140,** 585 (1949)

55. G. V. LeRoy, *Proc. Inst. Med.* (*Chicago*) **18,** 63 (1950); also E. H. Reinhard *et al.*, *J. Lab. Clin. Med.* **31,** 107 (1946)
56. H. L. Friedell, J. P. Storaasli, *J. Clin. Invest.* **28,** 1308 (1949)
57. A. Marshak, *J. Clin. Invest.* **28,** 1324 (1949)
58. J. H. Lawrence, L. R. Wasserman, *Ann. Internal Med.* **33,** 41 (1950)
59. B. V. A. Low-Beer, *Am. J. Roentgenol. Radium Therapy* **58,** 4 (1947)
60. M. T. Friedell *et al.*, *Arch. Internal Med.* **83,** 608 (1949)
61. M. T. Friedell, W. Indeck, F. Schaffner, *Arch. Internal Med.* **85,** 667 (1950)
62. A. S. Weisberger *et al.*, *J. Clin. Invest.* **29,** 336 (1950)
63. G. E. Moore, *Science* **106,** 130 (1947)
64. G. Boyack, G. E. Moore, D. F. Clausen, NUCLEONICS **3,** No. 4, 62 (1948); also G. E. Moore *et al.*, *Radiology* **55,** 344 (1950)
65. M. Ashkenazy *et al.*, *J. Lab. Clin. Med.* **34,** 1580 (1949)
66. G. Thoma, *Missouri State Med. Journal* (in press)
67. G. V. LeRoy, W. R. Tweedy, M. Ashkenazy, *J. Lab. Clin. Med.* (in press)
68. W. G. Myers, *Cancer Research* **10,** 234 (1950)
69. H. C. Dudley, G. E. Maddox, H. C. LaRue, *J. Pharmacol. Exptl. Therap.* **96,** 135 (1949)
70. H. C. Dudley, M. D. Levine, *J. Pharmacol. Exptl. Therap.* **95,** 487 (1949)
71. H. C. Dudley, J. I. Munn, K. E. Henry, *J. Pharmacol. Exptl. Therap.* **98,** 105 (1950)
72. H. C. Dudley, *J. Am Chem. Soc.* **72,** 3822 (1950)
73. P. F. Hahn *et al.*, *Science* **93,** 87 (1941)
74. L. Hahn, G. Hevesy, *Acta Physiol. Scand* **1,** 3 (1940)
75. G. Hevesy, O. Rebbe, *Acta Physiol. Scand.* **1,** 171 (1940)
76. G. Nylin, *Brit. Heart J.* **7,** 81 (1945)
77. H. M. Nachman *et al.*, *J. Clin. Invest.* **29,** 258 (1950)
78. A. F. Reid, M. K. Orr, *J. Clin. Invest.* **29,** 313 (1950)
79. R. J. Soberman, J. R. Krevans, R. P. Keating, *Proc. Soc. Exptl. Biol. Med.* **73,** 87 (1950)
80. H. S. Mayerson *et al.*, *Am. J. Physiol.* **155,** 232 (1948)
81. J. Fine, A. M. Seligman, *J. Clin. Invest.* **22,** 285 (1943)
82. J. Fine, A. M. Seligman, *J. Clin. Invest.* **23,** 720 (1944)
83. H. Krieger *et al.*, *Proc. Soc. Exptl. Biol. Med.* **68,** 511 (1948)
84. J. P. Storaasli *et al.*, *Surg. Gynecol. Obstet.* **91,** 458 (1950)
85. H. Krieger, *et al.*, *Proc. Soc. Exptl. Biol. Med.* **73,** 124 (1950)
86. K. R. Crispell, B. Porter, R. T. Nieset, *J. Clin. Invest.* **29,** 513 (1950)
87. R. T. Nieset *et al.*, *Am. J. Physiol.* **155,** 226 (1948)
88. L. Wish, J. Furth, R. H. Storey, *Proc. Soc. Exptl. Biol. Med.* **74,** 644 (1950)
89. H. N. Eisen, A. S. Keston, *J. Immunol.* **63,** 71 (1949)
90. J. J. Gray, K. Sterling, *Science* **113,** 179 (1950)
91. B. C. Smith, E. H. Quimby, *Surg. Gynecol. Obstet.* **79,** 142 (1944)
92. S. S. Kety, *Am. Heart J.* **38,** 321 (1949)
93. F. W. Cooper, Jr., *Southern Med. J.* **42,** 870 (1949)
94. M. Prinzmetal *et al.*, *J. Am. Med. Assoc.* **139,** 617 (1949)
95. G. B. Forbes, A. M. Perley, *J. Lab. Clin. Med.* **34,** 1599 (1949)
96. H. P. Wright, S. B. Osborn, D. G. Edmonds, *J. Obstet. Gynaecol. Brit. Empire* **56,** 36 (1949)
97. M. F. Levitt, M. Gaudino, *Am. J. Physiol.* **159,** 67 (1949)
98. L. L. Layton, D. Frankel, *Cancer* **2,** 1089 (1949)
99. L. D. Marinelli, *J. Clin. Invest.* **28,** 1271 (1949)
100. P. F. Hahn, C. W. Sheppard, *Ann. Internal Med.* **28,** 598, (1948); also P. F. Hahn, E. L. Carothers, NUCLEONICS **6,** No. 1, 54 (1950)
101. H. B. Jones, C. J. Wrobel, W. R. Lyons, *J. Clin. Invest.* **23,** 783 (1944)
102. E. L. Dobson *et al.*, U.S. Atomic Energy Commission AECD-2055 (Apr., 1948)
103. J. W. Gofman, *J. Lab. Clin. Med.* **34,** 297 (1949)
104. E. L. Dobson *et al.*, *J. Lab. Clin. Med.* **34,** 305 (1949)
105. H. Allen, L. Hempelman, H. Womack, *Cancer Research* **5,** 239 (1945)
106. P. F. Hahn *et al.*, *J. Lab. Clin. Med.* **32,** 1442 (1947)
107. H. Goldie, P. F. Hahn, *Proc. Soc. Exptl. Biol. Med.* **74,** 634, 638 (1950)
108. P. F. Hahn (personal communication)
109. G. Williams (personal communication)
110. A. I. Sherman, J. F. Nolan, W. M. Allen, *Am. J. Roentgenol. Radium Therapy* **64,** 75 (1950)
111. A. I. Sherman, W. M. Allen, M. D. Bonebrake, Abstracts of Roentgen Ray Soc. Meeting (St. Louis) (1950)
112. T. H. Clarke, G. V. LeRoy, *Proc. Inst. Med.* (*Chicago*) **18,** 64 (1950)
113. J. H. Müller, P. H. Rossier, *Experientia* **3,** 75 (1947)
114. J. H. Müller, *Bull. Schweiz. Akad. Med. Wiss.* **5,** 484 (1949)
115. D. M. Wallace, R. J. Walton, W. K. Sinclair, *Brit. J. Urol.* **21,** 357 (1949)
116. G. M. Haik, *New Orleans Med. Surg. J.* **102,** 504 (1950)
117. T. Kelly *et al.*, U.S. Atomic Energy Commission AECD-2024-M (Aug., 1947)
118. M. H. Block *et al.*, *J. Lab. Clin. Med.* **33,** 1649 (1948)
119. R. L. Straube *et al.*, *Proc. Soc. Exptl. Biol. Med.* **69,** 270 (1948)
120. J. H. Lawrence, J. G. Hamilton, editors, "Advances in Biological and Medical Physics," Vol. 1, pg. 28 (Academic Press Inc., New York, 1948)
121. P. F. Hahn, "Manual for Radioisotope Therapy" (Academic Press, Inc., New York, 1950)
122. Progress Report, Southern Research Institute (Aug. 15, 1950)

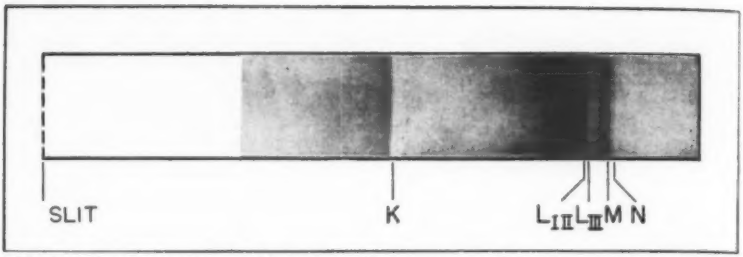


FIG. 1. Electron spectrum of lutetium-177 showing the *K*, *L*, *M*, and *N* lines due to a single 113.1-kev gamma ray

Nuclear Energy Levels for Some Long-lived Isotopes

Many improvements have been introduced in the techniques used to study electron spectra emitted by radioactive nuclei. This progress is reflected in the results obtained by photographic spectrometers and graphically presented here by the energy-level schemes for several long-lived heavy isotopes

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MUCH PROGRESS has been made in evaluating precisely the energies of emitted gamma rays, and for many radioisotopes it is now possible to construct energy-level schemes such that transitions between the proposed levels yield the observed gamma energies.

The beta spectrum of a pure radioactive emitter consists of a continuous characteristic distribution of electrons varying from zero up to a certain definite maximum upper limit of energy. Superimposed upon this continuous distribution may be many groups of electrons, each group having a definite unique energy. In a photographic magnetic spectrometer these electron groups appear as sharp spectral lines.

As early as 1917 it was suggested by Rutherford (*1*) that these electron groups might arise from a process now known as "internal conversion," in which a gamma ray from the nucleus gives up its energy completely to an orbital electron in the same atom. The electron thus escapes with an energy equal to that of the gamma ray minus its original binding energy. The electron may be in the *K*, *L*, *M*, or *N*, etc., shell of the atom. Thus, a unique gamma ray from a collection of radiating atoms will give as many electron groups as there are different orbital electrons.

These binding energies for the orbital electronic levels are known quite pre-

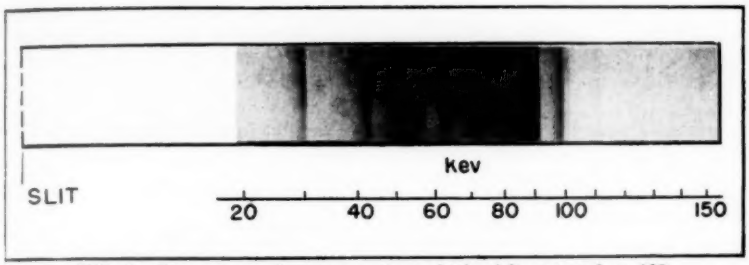

FIG. 2. Low-energy electron spectrum obtained from tantalum-182

cisely from X-ray studies. The observed differences in energy between the electron groups should therefore coincide with the known *K-L-M* differences from the X-ray levels in the same element. A typical group of such electron lines associated with a single gamma ray is shown in Fig. 1. This spectrum was obtained from radioactive lutetium. Since the gamma ray is emitted after a beta ray has left the nucleus, the *K-L-M* differences are characteristic of the next heavier element, namely, hafnium.

To obtain reasonably sharp electron lines, it is necessary that the electron source be as nearly massless as possible. This is to avoid a loss in energy by the electrons through absorption, a loss suffered in getting out of the specimen. Also the magnetic field in the spectrometer must not change during an exposure, and the geometry of the slit system must be favorable. Under these conditions, the spectrometer becomes a powerful tool because it identifies the atomic number of the emitting isotope without any chemical reaction being carried out. Long-lived emitters are particularly favorable for study by this method.

Certain radioisotopes are found to yield a great many electron lines, thereby indicating the emission of not one but several gamma rays. The identification of each group of electron lines associated with a single gamma ray is then not always easy. As an example of a complicated radioactive decay process, Fig. 2 shows only a portion of the electron spectrum obtained from radioactive tantalum.

It is now possible through the Atomic Energy Commission to obtain certain elements enriched in particular mass numbers. A comparison of the radiations from the isotopically enriched material, following its activation in a pile with the radiations from the natural element similarly treated, often is a vital aid in the correct assignment of the radioactivity.

After evaluating the energies of the gamma rays from a particular isotope, one can speculate on the arrangement of energy levels that could yield the gamma energies, as transitions between levels. In many cases, it has now been found possible to propose level schemes which, though complicated, appear to fit the observed data with remarkably good agreement.

The present state of nuclear spectroscopy may be said to correspond to X-ray spectroscopy as it existed about 1916. Information is accumulating rapidly on the many radioactive nuclei, and it is hoped that important significant generalizations may soon be made relating the growth in nuclear structure with some orderliness in the level scheme.

A rather complete summary of the energy levels in light nuclei, together

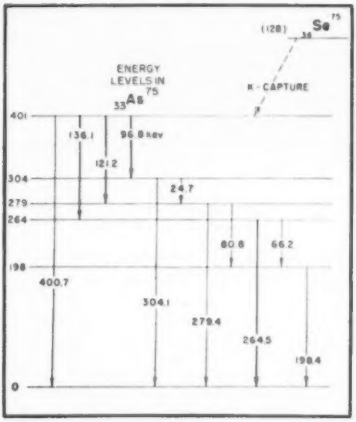

FIG. 3. Energy levels in arsenic-75 following K-capture in selenium-75

with references, has been compiled (*2*) by Lauritsen. The levels in these light nuclei are, in general, widely spaced, that is, expressed in Mev. For the heavier elements of simpler structure, an extensive but incomplete survey has recently been published (*3*).

To establish the fine structure of the gamma radiation, a high resolving power is essential. The widely used electron-lens spectrometers, even with the greatest care, are usually inadequate. A group of several closely spaced electron lines have often been reported as a single slight peak on the distribution curve.

It is the purpose of this report to present the results obtained by photographic spectrometers for a number of long-lived, heavy nuclei that are particularly prolific in gamma-ray yield. The proposed level schemes are presented graphically and include the most recent values for the energies of the beta and the gamma radiations.

In the original papers for each element, the energies of the electron lines are tabulated so that any alternate interpretation may be checked. For some of the elements, higher-energy gamma rays are known to exist, but they have not been evaluated with sufficient accuracy to be included in the figures. References are given to the previously published work for each isotope.

RESULTS

Selenium-75 decays (*4*) by K-capture to arsenic-75 with a half-life of 128 days. There now appear to be eleven gamma rays emitted by the excited arsenic-75 nucleus, all of which fit very satisfactorily the arrangement shown in Fig. 3. The specimen of selenium-74 used in this investigation had been enriched by the Oak Ridge National Laboratory from a normal abundance of 0.87% to 12.08%, and kindly made available for irradiation in the pile.

Silver-110 with a half-life of 270 days decays (*5*) both by the emission of gamma radiation followed by beta decay to cadmium-110, and by beta emission followed by gamma radiation

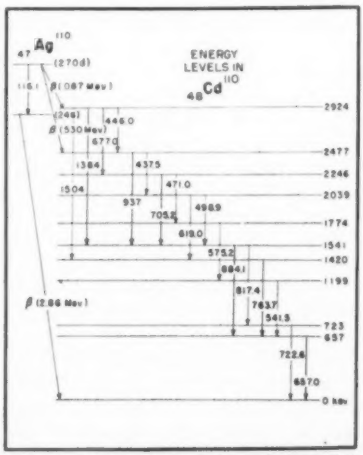

FIG. 4. Energy levels in cadmium-110 following beta emission from silver-110

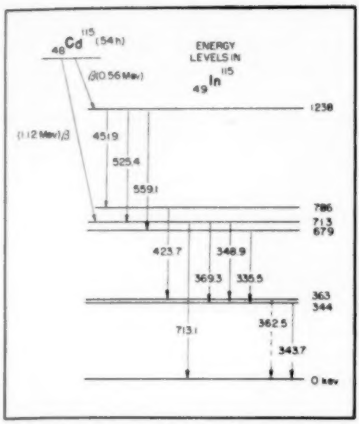

FIG. 5. Energy levels in indium-115 following beta emission of cadmium-115

to the same final state. The beta spectrum was found by Siegbahn to be complex, with upper limits at 87.53 and 2,860 kev. The many gamma rays now found may be combined with the beta energies to indicate the level scheme shown in Fig. 4. Two competing modes of decay are observed. In one branch, a gamma ray of energy 116.1 kev is first emitted to yield metastable silver-110 of half-life 24 seconds which decays by beta emission to stable cadmium-110. Along the other branch, beta emission occurs first, followed by multiple gamma emission.

Cadmium-115 appears (*6*) to be isomeric with half-lives of 42.6 days and 54 hours. Following beta emission, both activities terminate in indium-115. Ten gamma rays appear to be associated with the short-lived decay. Isotopes of cadmium, one enriched in mass 108 and another enriched in mass 114, were made available for this investigation. The level scheme in indium-115 suggested by the observed gamma energies is shown in Fig. 5. From the specimen enriched in mass 108, radioactive cadmium-109 was formed. This isotope decays with a half-life of 250 days by *K*-capture to silver-109, which emits a strong gamma ray of energy 87.5 kev.

Iodine-131, which is widely used in medicine, emits several gamma rays following a complex beta emission. Its level scheme has been of particular interest and many publications have appeared (*7*) on the subject. Using a bent quartz crystal spectrometer, DuMond (*8*) was able to evaluate precisely the wavelengths of three of the emitted gamma rays. These accurately determined values may now be used in calibrating other spectrometers.

Iodine-131, whose half-life is 8 days, appears to decay by a principal beta emission of 600 kev to excited xenon-131 which emits at least five gamma rays of 80.1, 177.0, 284.1, 364.2, and 637-kev energies. In a competing decay process, about 15% of the nuclei decay with beta emission variously reported as 250 ± 30 up to 315 ± 20 kev to metastable xenon of 12-day half-life. Two gamma rays in succession with energies of 163.6 and 723 kev may be emitted by this metastable xenon on its decaying to the stable state. The radioactive 12-day xenon has been chemically separated from the iodine by Brosi, DeWitt, and Zeldes.

As the composite specimen is allowed to age, the electron lines giving rise to the 163.6-kev gamma ray are definitely found to increase in strength relative to the other observed electron lines. This is demonstrated in Fig. 6*a* which shows two successive exposures for the energy region including the 163.6 and the 177.0-kev gamma rays. This places the 163.6-kev ray in the longer-lived decay branch. Deutsch has found evidence of coincidence between the 637-kev gamma and the 315-kev beta radiations; this would indicate placement of the high-energy gamma ray also in the metastable branch. This

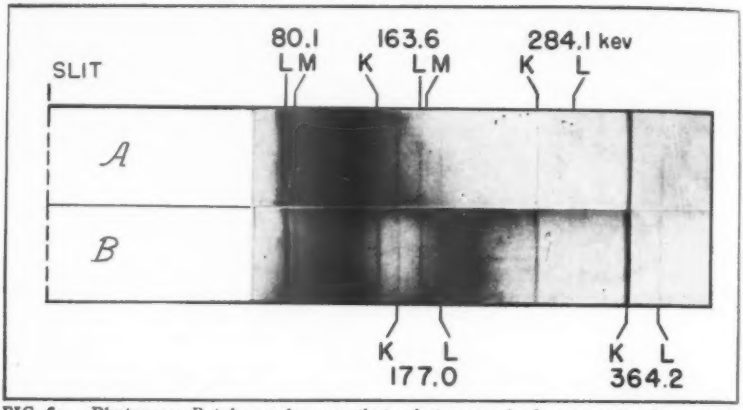

FIG. 6*a*. Photogram *B*, taken subsequently to photogram *A*, shows greater decrease in intensity for the 177-kev electron lines than for the 163.6-kev lines

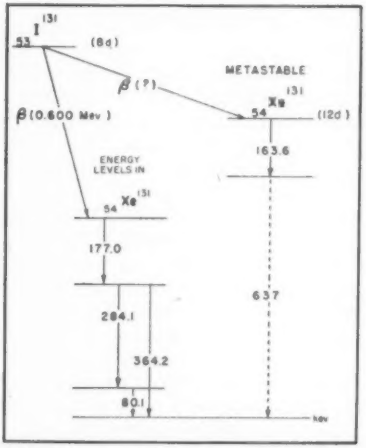

FIG. 6*b*. Tentative level scheme for xenon-131 following beta emission from iodine-131

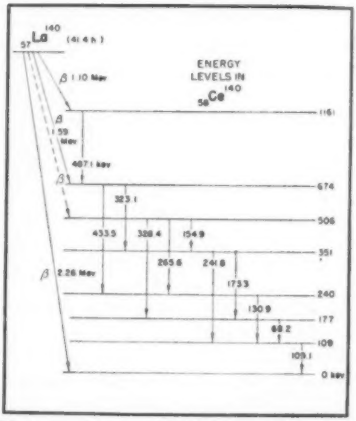

FIG. 7. Energy levels in cerium-140 following beta emission from lanthanum-140

assignment is at present being checked by a continued long series of photographic exposures. The level scheme shown in Fig. 6*b*, while considered tentative, is in agreement with most current data. One requirement of the proposed scheme would be a revision upward in the value of the low-energy beta ray. This is not unreasonable.

Lanthanum-140 is derived (*9*) from the single stable isotope of mass 139 by neutron capture. A highly purified specimen was found to decay with a half-life of 41.4 hours and showed 16 electron lines interpretable as due to eleven gamma rays in cerium-140. The beta spectrum had been reported by Osborne and Peacock to be complex with energies of 0.90 (20%), 1.40

(70%), and 2.12 (10%) Mev. A later investigation at Indiana resolved the beta distribution to give 1.37, 1.67, and 2.26 Mev. The energy level scheme shown in Fig. 7 quite satisfactorily accommodates the observed low-energy gamma rays and the averaged beta-energy values. Other higher-energy gamma rays are known to be present.

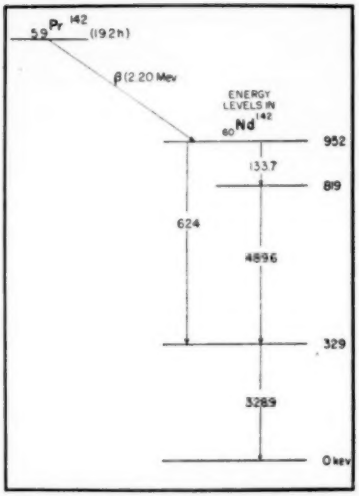

FIG. 8. Level scheme proposed for neodymium-142 following beta emission from praseodymium-142

Praseodymium exists as a single stable isotope of mass 141 and on neutron capture yields (*10*) a radioactivity of half-life 19.2 hours. Following beta emission, four gamma rays are observed by internal conversion in neodymium-142 and an additional high-energy gamma ray by absorption at about 2.1 Mev. The beta upper limits of energy are not known with accuracy so that only a tentative scheme is proposed; see Fig. 8.

Europium has been the subject of many reports (*11*). The two stable isotopes of mass 151 and 153 convert by neutron capture to radioactive euro-

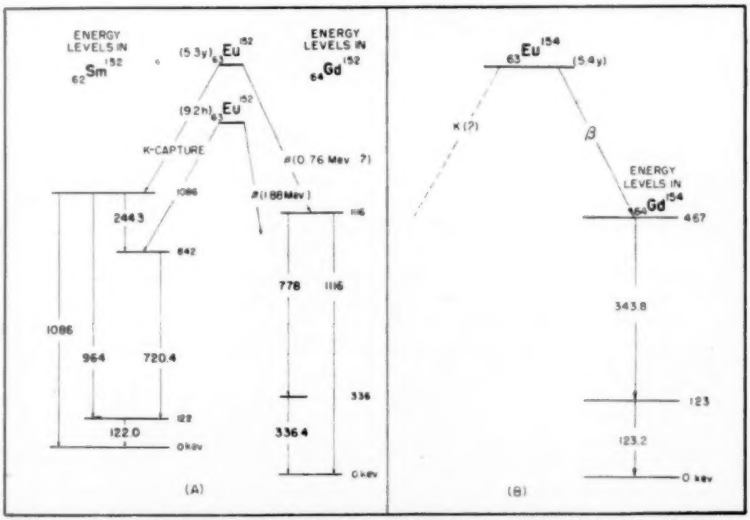

FIG. 9. (*A*) Proposed decay scheme for radioactive europium-152. (*B*) Tentative plan for the decay of radioactive europium-154

pium-152 and 154, whose half-lives are 5.3 and 5.4 years, respectively. A short-lived 9.2-hour activity is also known to exist, and it must be isomeric with one of the long-lived isotopes. On observing gamma rays, it is accordingly difficult to be sure from which isotope they originate. From various considerations, the decay plans shown in Fig. 9 seem at the present time to fit best all the observed data. Many of the gamma rays are emitted following *K*-capture and are thus in samarium while others follow beta emission and are in gadolinium. Until separated isotopes are studied, there can be no assurance that the mass assignments are correct.

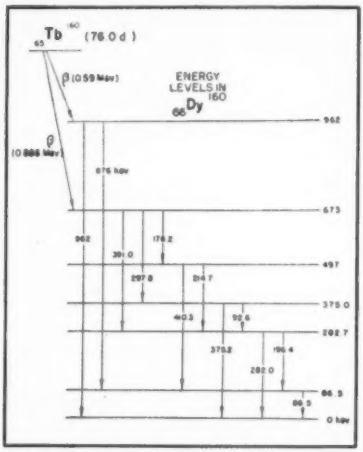

FIG. 10. Energy levels in dysprosium-160 following beta emission from terbium-160

Terbium-160 is created (*12*) by neutron capture in the single stable isotope of mass 159. It is isomeric with half-lives of 3.9 hours and 76 days. Over forty electron lines are observed from the long-lived activity and yield at least twelve gamma rays in dysprosium, following beta emission from terbium. The gamma rays fit remarkably well on the level scheme proposed in Fig. 10. The beta spectrum is known to be com-

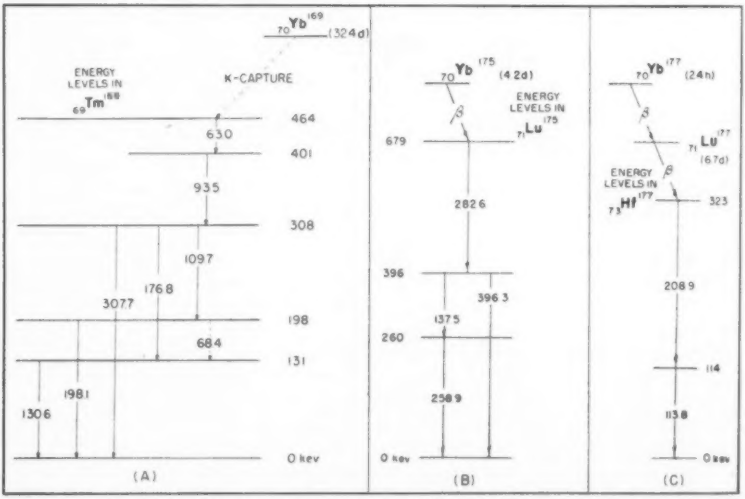

FIG. 11. (*A*) **Level scheme for thulium-169 following *K*-capture in ytterbium-169.** (*B*) **Level scheme for lutetium-175 following beta emission from ytterbium-175.** (*C*) **Excited levels in hafnium-177 following a double beta emission from ytterbium-177**

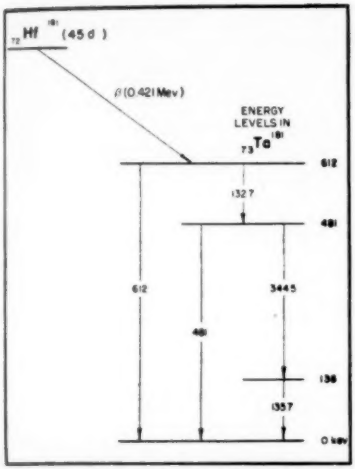

FIG. 12. Energy levels in tantalum-181 following beta emission from hafnium-181

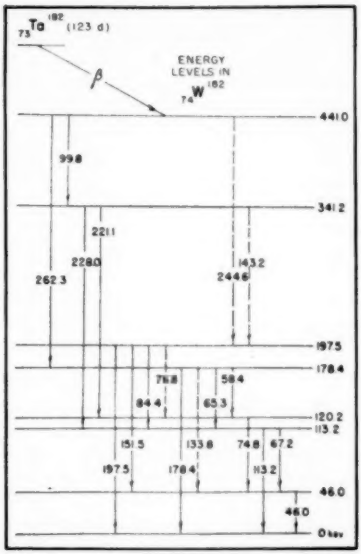

FIG. 13. Energy levels in wolfram-182 following beta emission from tantalum-182

plex and has been reported to consist of three components with upper limits of 396, 521, and 860 kev, each with considerable uncertainty. These values with adjustments are well accommodated by the proposed level arrangement.

Ytterbium exists in nature as seven different stable masses so that, when irradiated in the pile several radioactive isotopes can be made. Continued study (*13*) of this element in spectrometers indicates that three longer-lived activities are produced. Ytterbium-169 with a half-life of 32.4 days decays by *K*-capture to thulium-169 with the emission of eight gamma rays. This suggests a level scheme as shown by (*A*) in Fig. 11.

Ytterbium-175, whose half-life is 4.2 days, decays by beta emission to lutetium-175 followed by the emission of four gamma rays that may be arranged as shown by (*B*) in Fig. 11. Ytterbium-177, whose half-life is 2.4 hours, decays by beta emission to lutetium-177 which in turn decays with a half-life of 6.7 days by beta radiation to hafnium-177. Two gamma rays are associated with this process as indicated by (*C*) in Fig. 11.

Hafnium-181, whose half-life is 55 days, emits (*14*) many electron lines following its beta decay to tantalum-181. Five well-confirmed gamma rays may be arranged as indicated in Fig. 12. Certain accompanying weaker electron lines suggest other yet unresolved radiation. Radioactive hafnium-175 could also be made by the same irradiation in the pile. It has been reported to have a half-life of 70 days, decaying by *K*-capture to lutetium-175. Gamma rays of energy 88.7 and 342.1 kev are associated with this activity.

Tantalum-182, whose half-life is 123.5 days, is (*15*) perhaps the most

prolific emitter of electron lines of all the known radioactive isotopes. Fourteen strong gamma rays of relatively low energy have been identified, and several additional gammas, some with much higher energies, are known to exist. Four of the weaker gamma rays shown as dotted transitions, together with the fourteen strong gamma rays are remarkably well accommodated by the energy level scheme shown in Fig. 13. Some additions must later be made to this structure to satisfy the higher-energy gamma rays when they are precisely evaluated.

Protactinium-233 is derived (*16*) by beta emission from thorium-233 whose half-life is 23.2 minutes. The half-life of protactinium-233 is 27.4 days and, by beta emission, it converts to excited uranium-233 from which about thirteen gamma rays are emitted. These gamma rays are very satisfactorily accommodated by the simple scheme of six levels shown in Fig. 14.

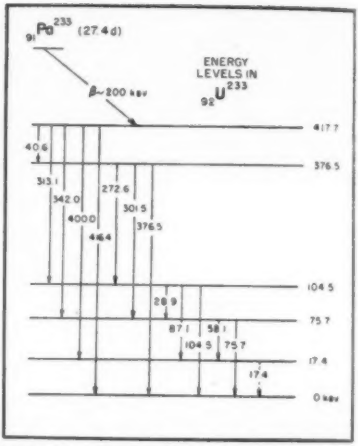

FIG. 14. Energy levels in uranium-233 following beta emission from protactinium-233

Other Elements: It appears that most of the newly created heavy radioactive isotopes are good subject material for gamma-ray studies.

Many radioactive bodies are found to emit only one or at most a few gamma rays; thus no level scheme need be presented to show the decay. Since the values of the energies that have been determined with considerable accuracy

Gamma Energies From Some Additional Isotopes

Z	*Isotope*	*Half-life*	*Gamma Energies* (kev)
26	Iron-59	46 d	85.1, 134.8
42	Molybdenum-99	68.3 h	139.6, 167.6, 179.3, 780
49	Indium-114	48 d	190.9
52	Tellurium-123	90 d	88.7, 159.3
52	Tellurium-125	60 d	35.5, 109.5
67	Holmium-166	27.7 h	81.0
69	Thulium-170	120 d	84.3
71	Lutetium-177	6.7 d	113.1, 208.6
74	Wolfram-187	25.0 h	133.7
75	Rhenium-186	91 h	122.7, 135.8, 640
75	Rhenium-188	16 h	153.6
76	Osmium-191	17 d	129.1
79	Gold-198	2.7 d	411.2
79	Gold-199	3.4 d	65.0, 76.6, 98.3, 103.0, 129.2, 131.4, 133.7, 138.6, 157.6

may be of interest, these results are summarized in the tabulation on the opposite page.

Many other elements have been studied, but the apparent results need confirmation. Future study will be particularly aided by the use of original elements that are enriched in the electromagnetic separator in particular mass numbers. Iridium-192 is a copious emitter of electron lines. Because previously reported nuclear level schemes need some correction, a report on this isotope is deferred.

This continued investigation has been possible by the excellent cooperative effort of a revolving research staff among whom have been: F. B. Shull, R. G. Shreffler, C. M. Fowler, E. Salmi, J. Sazynski, W. C. Rutledge, H. B. Keller, A. E. Stoddard, C. E. Branyan, J. M. LeBlanc, and W. J. Childs.

The project has received the joint support of the Atomic Energy Commission and the Office of Naval Research under Research Contract N5 ori, Task Order III.

The work on protactinium was carried out on spectrometers located at the Argonne National Laboratory by Mr. H. B. Keller under the supervision of Dr. C. O. Muehlhause.

BIBLIOGRAPHY

1. E. Rutherford, *Phil. Mag.* **34,** 153 (1917)
2. T. Lauritsen, Nuclear Science Series Report No. 5, National Research Council (1949)
3. A. Mitchell, *Revs. Mod. Phys.* **22,** 36, (1950)
4. C. V. Kent, J. Cork, *Phys. Rev.* **61,** 389 (1942); E. Jensen, L. Lazlett, W. Pratt, AECD-1836 (1948); H. Friedlander, L. Seren, S. Turkel, *Phys. Rev.* **72,** 23 (1947); W. Corvart, M. Pool, D. McCown, L. Woodward, *ibid.* **73,** 1454 (1948); J. Cork, W. Rutledge, C. Branyan, A. Stoddard, J. LeBlanc, *ibid.* **79,** 889 (1950)
5. A. Mitchell, *Phys. Rev.* **53,** 269 (1938); J. Livingood, G. Seaborg, *ibid.* **54,** 88 (1938); H. Reddemann, F. Strassmann, *Naturwissenschaften* **26,** 187 (1938); M. Deutsch, A. Roberts, L. Elliott, *Phys. Rev.* **61,** 389 (1942); **72,** 527 (1947); W. Rall, R. Wilkinson, *ibid.* **71,** 321 (1947); J. Cork, R. Shreffler, C. Fowler, *ibid.* **74,** 1657 (1948); K. Siegbahn, *ibid.* **75,** 1277 (1949); **77,** 233 (1950); J. Cork, W. Rutledge, C. Branyan, A. Stoddard, J. LeBlanc, *ibid.* **79,** 237 (1950)
6. J. Cork, J. Lawson, *Phys. Rev.* **56,** 291 (1939); A. Helmholz, *ibid.* **60,** 160 (1941); **70,** 982 (1946); L. Seren, D. Engelkemeir, W. Strum, H. Friedlander, S. Turkel, *ibid.* **71,** 409 (1947); J. Cork, W. Rutledge, A. Stoddard, C. Branyan, J. LeBlanc, *ibid.* **79,** 938 (1950)
7. G. Tape, J. Cork, *Phys. Rev.* **53,** 676 (1938); J. Livingood, G. Seaborg, *Phys. Rev.* **54,** 775 (1938); F. Metzger, M. Deutsch, *ibid.* **74,** 1640 (1948); G. Owen, D. Moe, C. Cook, *ibid.* **74,** 1879 (1948); B. Kern, A. Mitchell, D. Zaffrano, *ibid.* **76,** 94 (1949); A. Brosi, T. DeWitt, H. Zeldes, *ibid.* **75,** 1615 (1949); J. Cork, H. Keller, J. Sazynski, W. Rutledge, A. Stoddard, *ibid.* **75,** 1621 (1949); I. Feister, L. Curtiss, *ibid.* **78,** 179 (1950)
8. D. Lind, J. Brown, D. Klein, D. Muller, J. DuMond, *Phys. Rev.* **75,** 1544 (1949)
9. M. Pool, J. Cork, *Phys. Rev.* **51,** 1010 (1937); K. Weimer, M. Pool, J. Kurbatov, *ibid.* **63,** 67 (1943); R. Osborne, M. Peacock, *ibid.* **69,** 679 (1946); C. Mandeville, M. Scherb, *ibid.* **73,** 1434 (1948); L. Beach, C. Peacock, R. Wilkinson, *ibid.* **76,** 1624 (1949); J. Cork, H. Keller, W. Rutledge, A. Stoddard, *ibid.* **76,** 1886 (1949)
10. M. Pool, J. Cork, R. Thornton, *Phys. Rev.* **52,** 239 (1937); J. DeWire, M. Pool, J. Kurbatov, *ibid.* **61,** 544, 564 (1942); J. Cork, R. Shreffler, C. Fowler, *ibid.* **74,** 1657 (1948)
11. A. Tyler, *Phys. Rev.* **66,** 125 (1939); M. Inghram, R. Hayden, J. Reynolds, *ibid.* **71,** 130 (1947); **75,** 1500 (1949); F. Shull, *ibid.* **74,** 917 (1948); C. Muehlhause, Manhattan Project Report CP-3750 (1947); J. Cork, H. Keller, W. Rutledge, A. Stoddard, *Phys. Rev.* **77,** 848 (1950)
12. W. Bothe, *Naturwissenschaften* **31,** 551 (1943); B. Inghram, R. Hayden, D. Hess, *Phys. Rev.* **71,** 643, 743 (1947); N. Krisberg, M. Pool, C. Hibdon, *ibid.* **74,** 44 (1948); S. Burson, K. Blair, D. Saxon, *ibid.* **77,** 403 (1950); J. Cork, C. Branyan, W. Rutledge, A. Stoddard, J. LeBlanc, *ibid.* **78,** 304 (1950)
13. W. Bothe, *Z. Naturforch.* **4,** 173 (1946); M. Inghram, R. Hayden, D. Hess, *Phys. Rev.* **71,** 144, 270 (1947); J. Cork, H. Keller, W. Rutledge, A. Stoddard, *ibid.* **78,** 95 (1950)
14. G. Hevesy, H. Levi, *Kgl. Danske Videnskab. Selskab Mat.-fys. Medd.* **15,** 11 (1938); S. Bennedetti, F. McGowan, *Phys. Rev.* **70,** 569 (1946); M. Wiedenbeck, K. Chu, *ibid.* **75,** 226 (1949); G. Wilkinson, H. Hicks, *ibid.* **75,** 696 (1949); C. Mandeville, H. Scherb, W. Keighton, *ibid.* **75,** 221 (1949); J. Cork, A. Stoddard, W. Rutledge, C. Branyan, J. LeBlanc, *ibid.* **78,** 299 (1950)
15. O. Oldenberg, *Phys. Rev.* **53,** 35 (1938); V. Zumstein, J. Kurbatov, M. Pool, *ibid.* **63,** 59 (1943); C. Goddard, C. Cook, *ibid.* **76,** 1419 (1949); W. Rall, R. Wilkinson, *ibid.* **71,** 321 (1947); J. Cork, H. Keller, W. Rutledge, A. Stoddard, *ibid.* **78,** 95 (1950)
16. L. Meitner, F. Strassmann, O. Hahn, *Z. Physik* **109,** 538 (1938); G. Seaborg, J. Gofman, J. Kennedy, *Phys. Rev.* **59,** 321 (1941); E. Haggstrom, A. V. Grosse, E. Booth, J. Dunning, *ibid.* **59,** 322 (1941); P. Levy, *ibid.* **72,** 352 (1947); H. Keller, J. Cork, *ibid.* **79,** 1030 (1950)

Photosensitive Geiger Counters: Their Applications

Historical aspects and principles of operation of photon counters are discussed, and their role in research is reviewed. Development of the scintillation Geiger counter is outlined, and several forms of the device are illustrated here

By C. E. MANDEVILLE* and M. V. SCHERB†

A SHORT TIME after Geiger and Müller in 1928 introduced their tube for the detection of β-, γ-, and X-rays, a number of workers abroad and in this country turned their attention to the possibility of employing G-M counters as detectors of extremely weak intensities of visible and ultraviolet light.

Stimulated in part by the controversy which had raged on the Continent regarding Gurwitsch rays or so-called mitogenetic radiation, B. Rajewski (*1*) and others experimented with various types of G-M photosensitive tubes employing quartz windows and such metallic cathodes as cadmium, aluminum, nickel, etc., to detect radiation in the interval between 2,000 and 3,000 A. U. G. L. Locher (*2*) extended the spectral response of G-M counters into the visible region by the use of alkali metals and analine dyes. On occasion, he was able to produce tremendously sensitive counters in the visible region which were of some practical application in astronomical problems, but unfortunately he was plagued by lack of reproducibility and other difficulties.

From the early 1930's until after World War II, except for a few isolated instances, interest in photosensitive G-M counters waned, until a discovery by Scherb (*3*) of a method of sensitizing photosensitive counters and the advent of scintillation techniques employing photomultipliers again stimulated interest at the Bartol Research Foundation in the potentialities of photosensitive G-M tubes.

* Bartol Research Foundation of the Franklin Institute, Swarthmore, Pa.
† Nuclear Research Corporation, Philadelphia, Pa.

Principle of Operation

The interest in G-M tubes stems from the fact that the G-M tube is able to detect single electrons whether produced by ionization processes or by photoelectric emission. Theoretically, at least, a G-M photon counter should be far more sensitive than ordinary photocells which require the emission of a large number of electrons from the photosurface before a measurable current is obtained.

In its usual form, a photosensitive G-M tube consists of a cathode surface of mesh or solid cylindrical form encased in a jacket of ultraviolet-transmitting material such as quartz, Corning No. 9741 glass, or Corex D. For particular applications, a thin Pyrex bubble window or one of quartz may be used. Figure 1 (after Locher) shows the form a photon G-M counter may take for experimental researches on cathode surfaces and various gas fillings. A thin ½-mil glass bubble window will transmit wave lengths down to about 2,000 A. U. with little attenuation, and the ground-glass joint permits rapid removal and substitution of cathodes.

Light photons of the proper wave length impinging on the cathode surface

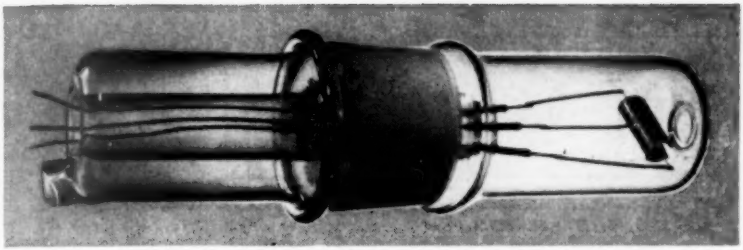

FIG. 1. Experimental arrangement for study of photosensitive G-M tubes

will cause one or more photoelectrons to be ejected, which will then fire the tube in the usual manner. Of course the tube will also fire if any type of ionizing radiation such as β- or γ-rays penetrates the envelope.

Research on photosensitive G-M counters resolves itself into two phases: 1. obtaining a spectral response in the desired region; 2. producing photoelectric surfaces of high quantum efficiency, where quantum efficiency is defined as the number of electrons ejected per quantum of light impinging on the cathode surface.

Spectral response. Most of the common metals have a threshold of response in the vicinity of 3,000 A. U. and a peak response at about 2,500 A. U. Since the applications of photon counter tubes in this region were, until recently, rather limited, numerous attempts have been made to shift the threshold of response towards longer wave lengths by employing alkali metals or discharge techniques. The difficulty with the alkali-metal approach is that, aside from lack of reproducibility, the low thermionic work function produces a large background at room temperature and necessitates cooling.

The discharge technique (*3*) seems to be a more promising approach since stable surfaces are produced with no increase in background, no decrease in counter life, and high quantum efficiencies at longer wave length.

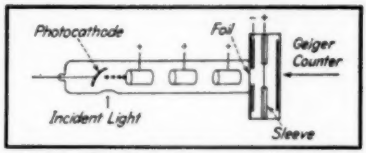

FIG. 2. Photosensitive counting device suggested by Ramsey

Quantum efficiency. Producing a surface of high quantum efficiency in a G-M photon counter is complicated by the fact that the gas mixtures tend to "poison" the surfaces and reduce the quantum efficiency markedly as compared to that obtainable under vacuum.

Ramsey of the Bartol Research Foundation has suggested a scheme for circumventing this problem wherein the quantum efficiency of the vacuum photocell is combined with the sensitivity of the G-M counter. As shown in Fig. 2, incident light passing through a thin glass bubble window into an evacuated chamber ejects photoelectrons which are then accelerated by a series of focusing anodes. Passing through a vacuum-tight window, which may take the form of a thin metallic foil on a supporting grid, these photoelectrons enter a G-M counter chamber. The cosmic-ray background of the counter tube is reduced by sleeving.

A number of workers have reported quantum efficiencies as high as 10^{-2} to 10^{-1} electron per quantum. Duffendach and Morris (*4*) found that some of their tubes equaled the quantum

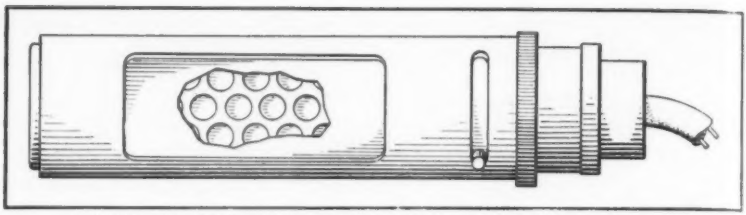

FIG. 3. Scintillation Geiger-counter tube and shell for α-β-γ survey

efficiencies of the best photomultipliers then developed.

For the ordinary G-M counter, the usual quantum efficiencies range from 10^{-3} to 10^{-4} photoelectron per quantum.

Applications

Flame detection and spectroscopy. One of the earliest applications for photon G-M counters was in the detection of ordinary flames by the ultraviolet emitted in the vicinity of 2,500 A. U. Weisz and Friedman (*5*) have demonstrated apparatus employing a G-M photon counter as a practically instantaneous detector of flames as small as that of a match 100 feet away.

In recent years, a number of spectroscopic applications have been developed (*6*) for photon G-M tubes in the deep ultraviolet region where the photographic plate techniques have been too laborious and photomultipliers have lacked the proper spectral response. A most promising application in this new field seems to be in the analysis of the amount of phosphorous in steel melts. As Bryan and Nahstoll (*6*) point out, G-M photon counters possess possibilities for determining the presence and quantity of elements difficult to analyze spectrographically. At the same time, they provide a powerful tool for the study of excitation in spectrography.

Biological detector. Aside from a few cases where the photon G-M counter has been used to monitor ultraviolet sources used in genetic and related investigations, the principal application in this field has been to the mitogenetic rays first postulated by Gurwitsch (*7*) in 1923.

Since the mitogenetic radiation supposedly radiated by such senders as onion roots, yeast cells, blood, etc., was thought to be of extremely weak intensity in the deep ultraviolet region below 2,500 A. U., numerous attempts were made during the early 1930's to detect such radiations with photon counters. Generally, negative results were obtained. For a review of this subject, the reader is referred to O. Glasser (*8*) and Hollaender and Claus (*9*).

Scintillation Geiger Counter

The period just after World War II was marked with the introduction of many different types of particle counters. Perhaps the most striking development of the era was the appearance of the scintillation counter (*10*). This instrument is commonly understood to consist of a crystal used in conjunction with a photomultiplier. Scintillations are induced in the crystal when it is irradiated by nuclear particles. The light pulses then eject photoelectrons from the photocathode of the photomultiplier. These photoelectrons are multiplied to give a detectable pulse.

The photomultiplier method has been recognized to have inherent advantages when compared with other methods of radiation detection, particularly in that very high detection efficiencies are obtained for γ-rays and very-high-speed counting is possible with negligible loss

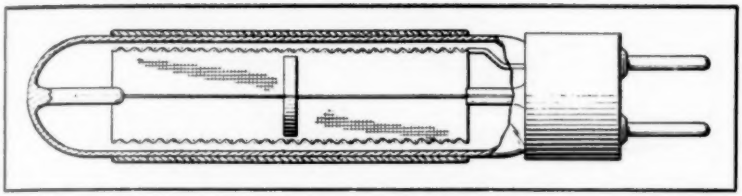

FIG. 4. Scintillation Geiger tube for the selective detection of α-particles in the presence of a β- and γ-ray background

Since 1947, it has seemed to the writers that the photosensitive Geiger-counter tube could also be used as a detector of short-lived fluorescent scintillations from crystals. A two-fold problem had to be met. Cathode surfaces of a high quantum efficiency had to be developed, and crystals fluorescing in the region of the peak of the spectral response of the cathode surfaces had to be found. The general history of the effort to attain the conditions essential to the development of a scintillation Geiger counter have been previously outlined (*11*). Briefly, it can be said that several different crystals, when irradiated by nuclear particles, have been observed to emit radiations in the deep ultraviolet in sufficient intensity to actuate photosensitive G-M counters. For example, scintillations from α-, β-, and γ-rays on NaCl-Ag have been detected with high efficiencies in photon counters (*11*).

A system of detection employing a scintillation Geiger counter offers a number of advantages over one using the photomultiplier technique.

1. Coverage of 360 degrees or directional detection is made possible by selective coating of the glass envelope of the photon counter.

2. There is no limitation as regards size of the detecting tube.

3. The associated electronic equipment is very simple and lends itself readily to portable operation.

4. The G-M tube is free of photomultiplier characteristics such as dark current, pulse size distribution, preamplification, cooling, etc.

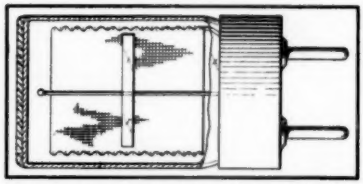

FIG. 5. End-on version of the selective α-detector

There remains the disadvantage of the finite dead time of the Geiger region. It seems probable that this difficulty can be circumvented by the operation of scintillation Geiger counters in the proportional region.

Some practical forms of the scintillation Geiger counter are shown in Figs. 3, 4, 5, 6, and 7.* A tube and accessories for an α-β-γ survey meter is shown in Fig. 3. This instrument would consist of a photon counter with a layer of the phosphor a few milligrams thick, within a perforated grid over which is placed a thin light-tight aluminum foil. An auxiliary shield is provided to differentiate between particles.

For selective detection of α-particles in a background of β- and γ-rays, the detecting tube might take the forms shown in Figs. 4 and 5. In Fig. 4, the counter is divided into two chambers by a thick ultraviolet-transmitting disk. An α-particle striking the phosphor coating would cause the isotropic emission of ultraviolet photons which would

* Patent applied for.

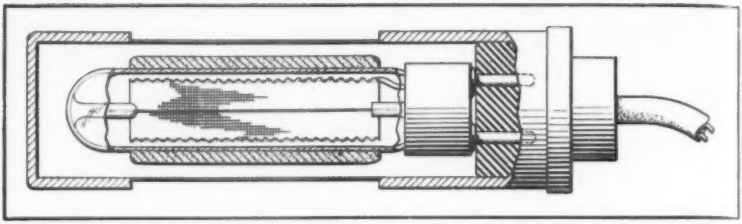

FIG. 6. Scintillation Geiger tube for β-ray detection

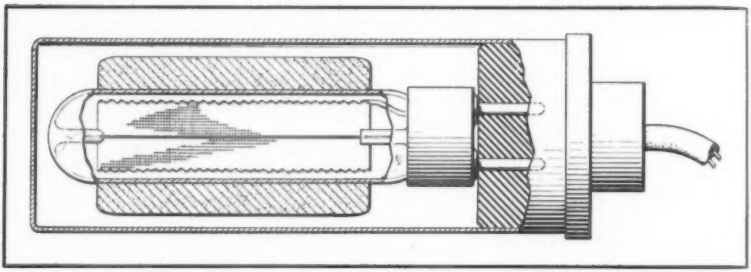

FIG. 7. Scintillation Geiger tube for γ-ray detection

discharge both chambers, whereas soft cosmic rays, β-rays, and γ-rays would fire only one chamber, most of the β-rays and Compton secondaries being stopped by the thick disk. An "end-on" version of the selective α-ray detector is diagrammed in Fig. 5.

A scintillation Geiger-counter β-ray detector might take the form shown in Fig. 6. The layer of fluorescing crystals is a few millimeters thick and is shielded from light by an aluminum section of about 20 mg/cm^2.

A high-efficiency scintillation G-M γ-ray detector is shown in Fig. 7. As indicated in the figure, the counter is surrounded by a layer of crystals a centimeter or more in thickness, and is sealed in a light-tight brass case.

Future

If the spectral response of scintillation Geiger systems can be extended to wave lengths greater than 3,000 A. U. by the use of suitable surfaces and the discharge technique, an increasing number of applications will be found. Preliminary efforts to extend the spectral response have resulted in the detection of scintillations from alpha particles on NaI-Tl. This crystal has a peak of emission at approximately 4,100 A. U.

BIBLIOGRAPHY

1. B. Rajewski, *Z. Physik* **63,** 576 (1930); *Ann. Physik* **20,** 13 (1934)
2. G. L. Locher, *Phys. Rev.* **42,** 525 (1932)
3. M. V. Scherb, *Phys. Rev.* **73,** 86 (1948)
4. O. S. Duffendach, W. E. Morris, *J. Optical Soc. Am.* **32,** 9 (1942)
5. P. B. Weisz, H. Friedman, U. S. Patent No. 2,507,359
6. F. R. Bryan, G. A. Nahstoll, *J. Optical Soc. Am.* **38,** 510 (1948)
7. A. Gurwitsch, "Die Mitogenetische Strahlung" (Julius Springer, Berlin, 1932)
8. O. Glasser, "Medical Physics," Vol. 1 (Year Book Publishers, Chicago, Ill., 1944)
9. A. Hollaender, W. D. Claus, *J. Optical Soc. Am.* **25,** 270 (1935); *Bull. Nat. Research Council (U. S.)* **100,** 1 (1937)
10. For a detailed discussion of the photomultiplier scintillation counter see R. W. Pringle, *Nature* **166,** 11 (1950)
11. C. E. Mandeville, H. O. Albrecht, *Phys. Rev.* **79,** 1010 (1950); also C. E. Mandeville, NUCLEONICS **7,** No. 4, 92 (1950)

Sensitivity of the Evaporation Method of Liquid-waste Monitoring

A statistical criterion for the detectability of radioactivity in waste liquids is stated here and applied, by way of example, to evaluation of minimum detectable concentrations for the effluent from Brookhaven's sewage-processing plant

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IN A WIDELY USED METHOD for determining the radioactivity of liquid wastes, a sample is evaporated to dryness and the activity of the solid residue is obtained by counting. Substances volatile under boiling will be lost and are not detected. This same method can be used to test for the presence of non-volatile radioactive substances in drinking water, rivers, ponds, etc. Thus, the sensitivity of this method is of considerable interest. One needs to know the minimum concentration of activity of various energies detectable with samples of various sizes, containing various amounts of solids.

At Brookhaven National Laboratory, we have been interested in determining this sensitivity for the effluent from our Imhoff sewage treatment tank, as well as for samples taken at other points in our liquid-waste system.*

Statistical criterion for sensitivity. Quite aside from questions of counting geometry, self-absorption, energy of particles, etc., a basic limitation is set upon the minimum detectable concentration of activity by the statistical nature of radioactivity.

It has been our custom to express the statistical uncertainty of measured counting rates with a 90% reliability figure. This figure, sometimes called the "reliable" error, is employed to avoid the implication of high accuracy that the use of probable error or standard deviation might convey to the uninitiated. By 90% reliability, we mean that there is a 90% chance that the counting rate averaged over an infinitely long time would fall within the designated limits.

In the case of beta counting, a "normal" statistical distribution is valid and the error in question is 1.645 times the square root of the total counts. Accordingly, as an arbitrary criterion for statistical detectability, we consider the minimum detectable activity to be that for which the 90% reliability deviation of the activity is equal to the activity as illustrated in the following example for the case of beta activity.

Background plus sample
19.8 ± 1.3 cpm (30-min count)
Background alone
18.0 ± 1.3 cpm (30-min count)
Sample alone
1.8 ± 1.8 cpm

The error for the sample alone is the square root of the sum of the squares of the errors of the two counts which

* Research done under the auspices of the Atomic Energy Commission.

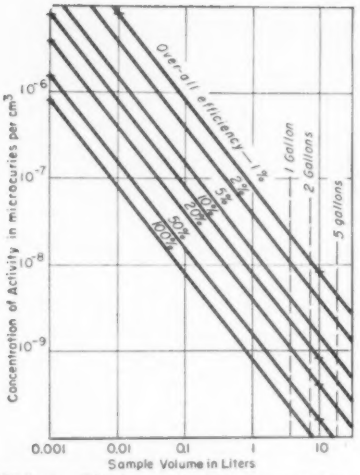

FIG. 1. Minimum detectable concentration with negligible absorption

are subtracted since a "normal" distribution holds. The long-term average of activity in this case has a 90% probability of lying between 0 and 3.6 cpm and a 95% probability of being greater than zero, again because the distribution is "normal."

The procedure just outlined is justifiable for beta counting where the number of total counts is well up into the region where the "normal" approximation is valid. In the case of alpha counting, however, backgrounds are much lower and the total number of counts for a minimum detectable amount of activity will be small unless excessively long counting times are used. However, it is shown below that, even in the case of alpha-counting situations where "normal" statistics do not hold, the criterion of minimum detectability using a formal computation based on "normal" statistics, will usually be a satisfactory approximation.

Minimum detectable concentrations of beta activity where absorption effects are negligible. Having established the criterion of detectability, it is easy to translate it into μc per cm^2 for samples of various volumes. The measured background of our beta counter is 18 or 19 cpm. Let us assume that all counts are of 30 minutes' duration, which is about as long as is practicable for routine monitoring where a large volume of work must be done with a counting room of reasonable proportions. This gives minimum detectable counts per minute of 1.8, as in the example.

The matter of over-all efficiency is considered below, but here we shall use an illustrative figure of 10%, which is about the value realized with a standard end-window G-M tube and a 10-cm^2 planchet or watch glass. The minimum detectable activity is then:

$$\beta \text{ activity} = \frac{(1.8)}{(0.1)(60)(3.7 \times 10^4)} = 8.1 \times 10^{-6}\ \mu c$$

This is typical of high-energy activities where the absorption of the tube window, air, and the sample itself are negligible. For low energies, as shown below, the over-all counting efficiency will drop to much lower values, and the minimum detectable activity will be correspondingly greater.

Some increase in sensitivity can be achieved by the use of a coincidence counting system to give a reduced background counting rate. For instance, if the background is reduced by a factor of four (a reasonable reduction for such a system), then the minimum detectable activity is reduced to approximately one half of the above amount. We have used only the single tube counter since its sensitivity is adequate.

The minimum detectable concentration of the activity in a particular sample will depend on the size of the sample, as shown in Fig. 1. Since, even for this case of negligible absorption, a considerable variation in over-all counting efficiencies is possible, depending on the type of counting arrangement, Fig. 1 shows a range of efficiency values.

Minimum detectable concentration of alpha activity where absorption effects are negligible. For alpha counting, "normal" statistics will not, in general, apply because the number of total counts is small and because a more careful consideration of statistical behavior is necessary. For instance, with our scintillation counters, background, as determined by a long count, is about 0.1 cpm. Thus the expected counts in 30 minutes would be 3 and a Poisson distribution should be used for a statistical analysis.

Fortunately, for the application desired here, the "normal" distribution is a surprisingly good approximation to the Poisson distribution even for total counts as small as 3 (see *Appendix*). Accordingly, the minimum detectable amount of alpha activity may be deduced by the same type of analysis as was used previously for beta counting without serious distortion of the statistical significance of the figure thus obtained. Using 30-minute counts as before, let us consider the following case.

Background plus sample

9 ± 5.0 counts in 30 min

Background alone

3 ± 2.8 counts in 30 min

Sample alone

6 ± 5.7 counts in 30 min

Thus the minimum detectable activity according to the criterion given above will correspond to about 6 counts in 30 minutes or 0.2 cpm. The amount of activity can be computed, as before, using the efficiency of our counter which is 15%.

$$\text{alpha activity} = \frac{0.2}{(0.15)(3.7 \times 10^4)(60)} = 6 \times 10^{-7}\ \mu c$$

This is considerably less than the value for beta counting. However, absorption effects are seldom negligible where alpha activity is involved and, in practice, this increased sensitivity is partly canceled out, even for a relatively energetic alpha emitter such as plutonium, because of the self-absorption of the sample or the reduction of sample volume made necessary by such self-absorption. Accordingly, a graphical presentation of minimum detectable concentrations for various volumes of sample, similar to that made for beta activity, is probably not worth while. Some analysis of the degree of limitation of the minimum detectable concentration by absorption effects follows.

Modified Beta Standards

One method of evaluating counting efficiency is to compute the ratio of observed counts per minute to known disintegrations per minute for a standard. This ratio is then used as an efficiency coefficient in evaluating rates of disintegration of unknown samples.

This method is sound, provided one is measuring the unknown sample under the same conditions of preparation, backing material, size and shape, particle energy, self-absorption characteristics, and counting conditions as applied to the efficiency determination. When dealing with samples that differ appreciably from a given standard in respect to these considerations, it is necessary either to apply corrections or to obtain a standard which has the same characteristics as the sample in question.

The application of corrections requires a detailed knowledge of the variables listed above for both the standard and the unknown and an understanding of the functional relationship between these variables and counting efficiency. Such corrections can sometimes be made rather easily by use of available data and physical laws. However, the preparation of a modified standard is frequently easier and more reliable, and it is this method that we have used in determining counting efficiency for sewage samples.

The standard used here for most beta counting is a RaD-E source approximately 1.5 cm in diameter. It is

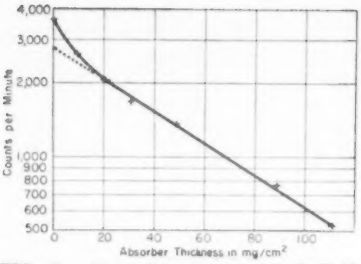

FIG. 2. Absorption curve with RaD-E source

mounted on a silver-palladium disk. The active deposit is very thin so that self-absorption by the standard is negligible. The sewage samples, on the other hand, are prepared by evaporating 500 ml of the Imhoff tank effluent down to approximately 5 ml which are then evaporated to dryness on a watch glass of 4-cm diameter.

It is quite obvious, on this basis, that the RaD-E standard is unsuitable for sewage assaying in that it differs from the sewage samples appreciably on each of the points enumerated above. It was therefore undertaken to prepare standard samples having characteristics identical within experimental errors with those of our unknown sewage samples. This was done by adding known amounts of activity to samples of sewage and following the regular processing routine. For each radioactive substance used, a series of standards with different weights of solid residue ranging from 0 to 100 mg was prepared. The substances were chosen to cover the energy range of greatest interest and were as follows: C^{14}—0.155 Mev (max.); Co^{60}—0.31 Mev; Sr^{90}—0.61 Mev; RaD-E—1.17 Mev; and P^{32}—1.71 Mev.*

* We are indebted to Drs. W. Miller and B. Burt of the Chemistry Department for carefully assayed samples of RaD and C^{14}. The Oak Ridge assays were used for the other three substances.

The disturbing effects of the Co[60] gamma ray and the Y beta that is associated with Sr^{90} were eliminated by making absorption curves and determining the soft component. Since this is a well-known procedure, details will not be given.

Beta counting efficiency with negligible self-absorption by the sample. To separate the effect of sample self-absorption from other effects, we first determined counting efficiency using

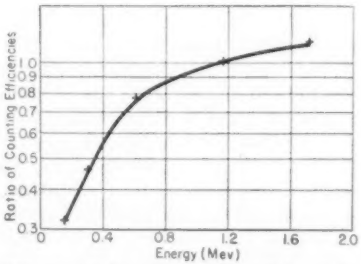

FIG. 3. Ratio of counting efficiency to that for RaD-E as a function of maximum beta energy—no self-absorption by the sample

the zero-absorption member of the RaD-E series of "spiked" samples. This sample, made by evaporation of 5 ml of water solution by the standard method, has negligible self-absorption.

A RaD-E standard emits beta particles of 0.025 and 1.17 Mev maximum energy in equal numbers, except in recently prepared sources. The counting rate for the more energetic beta particle may be determined by making an absorption curve and extrapolating the hard component back to zero absorber. This is illustrated in Fig. 2 in connection with the RaD-E sample just referred to. Since the deposit was known to consist of 29,500 dpm of RaD, the observed 2,800 cpm of D betas indicated an over-all efficiency of 9.5%. With the conventional RaD-E standard, the efficiency for the same shelf of

this counter was 20%. The change in efficiency is chargeable to the increase in area of the sample and the difference in backscattering between the silver-palladium and glass.

The way in which the energy of beta particles affects counting efficiency in the absence of appreciable self-absorption by the sample was determined by counting the various modified samples having negligible solids. The results are shown in Fig. 3 where the ratio of efficiency for the available energies to efficiency for RaD-E is plotted. The presence of some absorption in the counter window and in air even for RaD-E can be noted from this plot. Absorption of this type becomes quite appreciable for the energy of C^{14} and will depend strongly on the thickness of counter window and air path used in

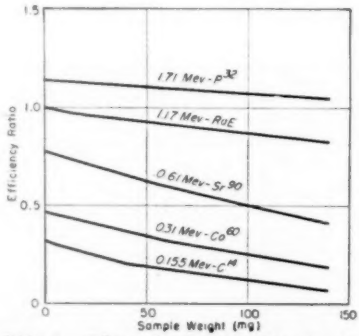

FIG. 4. Effect of self-absorption by the sample on counting efficiency (area 10 cm²)

any particular counting setup. A window thickness of about 2 mg/cm² is used in our β/γ counter.

Effect of self-absorption of the sample on beta-counting efficiency. To determine the effect of sample weight on counting efficiency, the full series of modified samples for each of the five beta emitters was counted. For each series, the ratios of counts with the modified sample to counts obtained with the sample of negligible self-absorption were computed. These ratios are plotted in Fig. 4. In the case of our normal sewage samples which have about 100 mg of solids, self-absorption is unimportant for a substance like P^{32} but very appreciable for C^{14}.

The over-all efficiency will be the product of the value for RaD-E with no self-absorption (9.5% in our case) and the ratios representing absorption effects given in Figs. 3 and 4. For C^{14} and a 100-mg sample, the reduction factor due to absorption will be 0.32×0.38, or 0.12. Thus the sensitivity of assay is drastically reduced by absorption for C^{14} and will drop rapidly for still softer radiations. The way in which over-all efficiency depends on both sample weight and particle energy is shown in Fig. 5 for the counting arrangement used to take data above.

Minimum detectable concentrations of beta activity. It is necessary now to evaluate the minimum detectable amounts of activity in the sewage effluent including the effects of absorption of beta particles in the sample, the measuring equipment, or the air. In addition to the considerations of sample volume and statistics discussed above, we now have both sample weight and

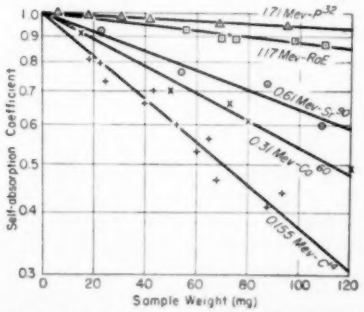

FIG. 5. Effect of sample weight and maximum beta-particle energy on over-all counting efficiency

energy of radiation as variables that will determine the minimum detectable concentration.

For a particular volume of sample and counting arrangement, a set of curves such as shown in Fig. 6 is useful. Here we have chosen a volume of 500 ml and a 10% efficiency for modified RaD-E samples of no self-absorption. For any sample, if the weight is known, mimimum detectable amounts of isotopes of various energies can readily be obtained.

Alpha Counting

A minimum detectable amount of alpha activity neglecting self-absorption by the sample has been given above. We have not investigated the effect of such self-absorption experimentally as was done for beta activity. However, a satisfactory idea of the limitations placed on alpha monitoring sensitivity can be obtained analytically. For this purpose, we shall use polonium alpha particles which have an energy of 5.3 Mev, a range in air of 3.83 cm or 4.6 mg/cm², and a range in aluminum of 5.7 mg/cm². A range of 5 mg/cm² should be a satisfactory rough figure for the material in sewage or water samples.

A sample prepared from 500 cm³ of the effluent from our sewage processing plant has about 0.1 gm of solids distributed over 10 cm². Thus a 200-cm³ sample giving an absorbing layer of 4 mg/cm² would be about as large as could profitably be used. Since

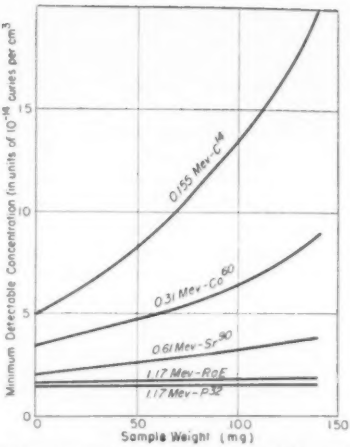

FIG. 6. Effect of sample weight and maximum beta-particle energy on minimum detectable concentration (500-cm³ sample)

the minimum detectable amount of alpha activity given above for no self-absorption was only 1/16 that for beta activity, we see that alpha assay is as sensitive as beta assay, even for energetic beta particles where samples of 2 or 3 liters can be used.

Minimum detectable concentration of polonium in sewage effluent will be:

$$\frac{6 \times 10^{-7}}{200} = 3 \times 10^{-9}\ \mu c/cm^3$$

Plutonium and a number of other alpha emitters have similar energies and a factor of two above or below polonium includes practically all others so that this figure is fairly representative.

SUMMARY

We have stated a statistical criterion for detectability of radioactivity in waste liquids and applied it to an evaluation of minimum detectable concentrations for the effluent from the Brookhaven National Laboratory sewage-processing plant. The results may be summarized as follows:

Isotope	P^{32}	C^{14}	Po
Particle	β	β	α
Sample volume (ml)	500	500	200
Minimum Detectable Concentration ($\mu c/cm^3$)	1.6×10^{-8}	1.8×10^{-7}	3.0×10^{-9}

APPENDIX

Normal Statistics as an Engineering Approximation to Poisson Statistics for Low Counting Rates

The use of a "normal" distribution in establishing a minimum detectable amount of activity results in a good approximation even for low counting rates for two reasons. In the first place, the Stirling approximation to the factorial, which is used for total counts in the "normal" approximation and not in the Poisson distribution, is a good one except for very low integers. For instance, the Stirling approximation to 3! is off by only 2.7% from the true value of 6. In the second place, when two Poisson distributions are subtracted, as in correcting a sample count for background, some of the asymmetry of the Poisson distributions is canceled out so that the difference is more closely approximated by a normal approximation. Since experimental errors in various parts of the assaying procedure will run 10% or more, the error involved in applying "normal" statistics is usually negligible.

By way of illustration, let us take a case where a 30-min background count yields 2 counts and a 30-minute sample count yields 7 counts. Applying "normal" statistics, we have:

Total count

$$7 \pm 1.645\sqrt{7} = 7 \pm 4.4$$

Background count

$$2 \pm 1.645\sqrt{2} = 2 \pm 2.3$$

Net activity

$$5 \pm 4.9$$

For this case, then, making a small adjustment from tables of normal statistics, there is a 95.4% probability that true activity of the sample is > 0.

Determining by Poisson statistics the statistical significance of the measured activity of 5 counts in 30 minutes entails a computation that is a bit lengthy but not too laborious if a computing machine is used. Using tables of probability for the Poisson distribution,* we tabulate values of probability that a count of 7 will be obtained when the true value of counts, as deduced from an infinite count, is 0, 1, 2, 3, etc. Then we do likewise for an observed count of 2. Now we determine the probabilities that the net activity should really be 0, −1, −2, −3, etc., by summing the products of appropriate probabilities from the two tabulations just mentioned. Lastly, we add up the probabilities that the true net activity is really 0, −1, −2, −3, etc., and subtract from one to get the probability that the observed net activity corresponds to a true activity greater than zero. The result obtained in this way is 92.7%, which compares favorably with the 95.2% probability obtained by blind use of the "normal" distribution.

Actually for an average rate as low as 0.1 cpm, 30-min counts have wide statistical distribution, and fairly large variations in true background will not be detected. We have found it preferable to periodically make a count of several hours and use the background figure obtained for all samples counted until the next long background count.

Naturally, if this procedure is to be followed, the counting apparatus must be free from spurious counts due to line transients or microphonics, a condition reasonably easy to achieve with a scintillation-type alpha counter. Good background values can be obtained overnight if line voltage is recorded continuously so as to detect interruptions in electrical service.

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* Karl Pearson, "Tables for Statisticians and Biometricians" (Cambridge University Press, New York, 1930).

PROPORTIONAL COUNTERS—II*

Building on the theory presented in the first article of this series, the author presents applicable design considerations. Special attention is given to neutron counters, to the use of radiators, and to methods for eliminating background effects

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A VERY CONSIDERABLE latitude is possible in the geometries and design of counters, so that the size and shape can readily be adapted to special problems. Cylindrical geometry is generally used and has become traditional, so that we usually think of a counter as a cylinder. Other geometrical arrangements of the electrodes are entirely possible, however. For example, spherical geometry may be used, or the electrodes may simply be parallel plates.

The advantages of the cylindrical design lie in ease of construction, since the wire along the axis automatically provides the high fields in its immediate vicinity which is necessary for building up the electron avalanches. As a practical matter, the wire should be between one and four mils in diameter, since a wire less than one mil in diameter is so fragile that ordinary handling may break it, and one five mils or more in diameter is so coarse that the voltage across the counter has to be increased by appreciable amounts to secure fields necessary for avalanche production.

Parallel plates provide the extreme example of high fields. Here the field is uniform, and for spacing of even a few millimeters, the operating voltage is usually many thousand volts. The second result of the parallel plate arrangement is small sensitive volume, which for many applications is undesirable. Thus, for most purposes a cylindrical counter geometry is the most convenient, although this may be modified when the application calls for it.

Counter size. The size, i.e., the length and diameter of the cylinder, is chosen to provide a counting rate of convenient magnitude. For example, in cosmic-ray work, where the intensities to be counted are usually low, very large counters suffice. The criterion should be that the maximum amount of information should be secured in minimum time. Proportional counters can be operated at rates up to 10^3 counts per second with very little loss of counts due to statistical overlapping, and with somewhat greater tolerance up to 10^4 c/sec.

The flux of particles to be detected through the counter will determine the optimum size. Except in the cosmic-ray case, the flux is seldom uniform, but if it is, the optimum area A, in cm^2 is given by

$$A = 10^{-3}i \qquad (1)$$

where i is the flux in particles of the type to be detected plus background per sec per cm^2. When the flux is not uniform over the area of the counter,

* Part I of this article appeared in the June, 1950, NUCLEONICS, page 5. Part III, detailing electronic circuitry associated with proportional counters, will appear in the near future.

this equation must be modified by making the appropriate integrations. If the counter is much larger than this optimum size, counts will be lost by overlapping, and in extreme cases the counter may be paralyzed and give quite erroneous readings. On the other hand, if the counter is smaller than the optimum size, time is wasted in accumulating data.

Corona discharge. Sometimes, where it is inconvenient to make a single counter of larger size, a series of counters may be arranged in parallel. The advantage of using small counters in parallel lies in the fact that the operating potential can be kept at a modest figure, and the same high-voltage supply can be used for the entire set of counters. Among the several reasons for keeping the voltage at a moderate value is that even a small amount of corona anywhere in the high-voltage supply system can induce pulses on the counter wire which will look electrically to the amplifier sufficiently similar to genuine counter pulses so that spurious counts will be recorded. A corona, it will be recalled, is not a steady discharge, but is a rapid series of individual spurts of ionization, with time constants of the same order as those of counter pulses.

Since moderate amplification is customarily used in proportional counter applications, favorable conditions for picking up induced spurious pulses exist, and it is especially important to make certain that the high-voltage power supply or any of the leads carrying the high voltage do not produce corona. The entire arrangement should be carefully tested with a high-gain oscilloscope before starting to make measurements. In general, corona can best be avoided by keeping the voltage as low as possible. Sharp points on any lead carrying the high voltage should be avoided. Good capacitors are important, for leakage paths across capacitors can also give spurious pulses. Further suppression of corona is possible by covering all high-voltage lines with some insulating material, so that they are not exposed to the atmosphere. One way of doing this is by painting the lines with wax.

Windows for counters. Windows must be provided so that a maximum amount of the radiation to be detected can reach the sensitive area inside the counter. In the cosmic-ray case, this is not a serious problem, for the radiation is usually sufficiently penetrating to reach the interior through whatever walls the counter may have. But in many other cases the window may become a serious problem.

In the design of windows, thought should be given to arranging structural features to minimize background. The use of heavy walls and shielding everywhere except at the window is often desirable; indeed, the window itself should whenever possible be chosen so as to be transparent to the radiation to be detected and opaque to the background radiation. This can often be approximated, if not fully attained, by careful consideration of the penetrating properties of the various kinds of radiation. Thus a lead shield around a neutron counter will be relatively transparent to neutrons while it is effective in reducing the charged-particle background.

Neutron Counting

There are essentially two types of neutron counters: those designed to detect slow neutrons preferentially, and those designed for fast neutrons. Let us first consider slow neutron detectors. Slow neutrons can best be detectee by arranging for the neutron to experience a nuclear interaction resulting in the emission of a heavily ionizing particle. Since there are only a few slow-neutron reactions which result in the emission of such particles, the possible choices

are limited. A few elements exhibit very large capture cross sections for slow neutrons, resulting in the emission of alpha particles. Among these, the largest cross sections are found for boron and lithium.

Lithium has the smaller cross section and is an inconvenient metal to use for construction purposes. Moreover, there is no convenient gas with molecules containing lithium as a component. Lithium, therefore, has been very little used, although lithium-lined ionization chambers have been constructed and do operate. Since lithium-lined chambers are not often used, are hard to construct, and are not as efficient as their boron counterparts, we shall confine our discussion to counters utilizing boron. The gas boron trifluoride is usually used in such counters.

The B^{10} nucleus has a high cross section for neutron capture. The cross section is known to be accurately inversely dependent on neutron velocity over a considerable energy range, from 0.01 volt, which is well below thermal, up to 10^5 volts. The reaction may be written

$$_5B^{10} + {}_0n^1 \rightarrow {}_3Li^7 + {}_2He^4 + \text{Energy} \quad (2)$$

The products of the reaction are an alpha particle and a lithium nucleus. The energy of the reaction may be calculated from the masses, and comes out as 2.9 Mev. The observed energy is around 2.5 Mev, which suggests that the lithium nucleus emerges in an excited state. The lithium nucleus is, by independent experiments, known to have a level at 0.4 Mev. With this interpretation, the equation balances energetically.

Conservation of momentum requires that the alpha particle shall have an energy of 1.6 Mev, while the lithium nucleus carries off 0.9 Mev. Since only two particles are involved, the two pieces fly off in opposite directions. This is especially important to remember when making efficiency calculations, for if capture takes place very close to the wall of the counter, and if one of the emergent particles is directed toward the wall and is absorbed in the wall, the other will still be directed out into the active volume of the counter and can produce a count.

The number of counts will be equal to the number of boron captures within the sensitive volume of the counter in unit time. The counting rate n, in c/sec, therefore, will be given by

$$n = ib\sigma = VLp \int i(v)\sigma(v)dv \quad (3)$$

where i is the flux of neutrons passing through the counter per cm² per sec, b is the number of boron atoms present in the entire sensitive volume, and σ is the cross section of the boron for capture of neutrons. Both the flux and the cross section are often velocity dependent, so we may write the equation in general as the last expression in Eq. 3. Here L is the Loschmidt number, 2.705×10^{19} molecules/cm³ at standard pressure and temperature, p the pressure in atmospheres, and V the volume of counter in cm³. This is an integral equation, and it is not possible to determine the neutron flux from observation of the counting rate unless the velocity of the neutrons is known. The quantity which can be determined is the neutron density. We recognize that the cross section is inversely dependent on the velocity, and that the flux, in neutrons crossing a cm² in unit time has the dimensions of density of neutrons per cm³ times the velocity, in cm/sec. Substituting these two quantities in Eq. 3, we may integrate and obtain

$$n = VLp\rho\sigma_B v_B \quad (4)$$

where ρ is the density of neutrons with all velocities per cm³ and σ_B is the capture cross section at the velocity v_B. Hence we see that the slow neutron counter measures the density of neutrons, or the number with all velocities

per cm³, and that the flux cannot be known unless the velocities are known. Since the velocity cannot be measured in the same experiment, evaluation of the flux requires subsidiary information. The property of measuring the density, and not the flux, is a general characteristic of all $1/v$ detectors and is well known in neutron physics.

It is only the B^{10} isotope which exhibits the (n,α) reaction. Since ordinary boron, as it occurs in nature, is a mixture of B^{10} and B^{11}, in the ratio of four parts of B^{11} and one of B^{10} in any sample, and since the isotope B^{11} is ineffective and plays the role of a diluting agent only, the isotope ratio must be taken into account in computing cross sections. In recent years, boron in which the B^{10} content has been enriched has become available through the Isotopes Division of the Atomic Energy Commission. The enriched isotope is in the form of a complex solid, $CaF_2 \cdot BF_3$. The usual enriched percentage is 96% B^{10} and the remaining 4% B^{11}.

Depleted B^{10} is also available, with 10% B^{10} and 90% B^{11}. This substance is useful for filling control counters, making evaluation of backgrounds possible. It is evident that if the counting rate of an enriched counter is a c/sec, and a depleted counter, filled to the same pressure of gas is b c/sec, then

$$a = 0.96n + c \qquad b = 0.10n + c \quad (5)$$

where n is the counting rate due to neutrons and c is the background counting rate. Solution of the two equations gives

$$n = (b + a)/0.86 \qquad c = (a - 9.6b)/8.6 \quad (6)$$

so that two identical counters, exposed to the same number of neutrons, but one containing enriched and one depleted boron, will allow determination of the neutron density and the background.

The background is important, for every counter will show a counting rate which results from events which it is not desired to measure. In the case of a neutron counter, such counters will have a background produced by all the events which result in the liberation of more than 2.5 Mev as ionization in the counter. Such events include contamination alpha particles, giant cosmic-ray showers, and nuclear disintegrations or "stars" which accompany cosmic-ray phenomena but which can also be induced by mesons. In addition to these, there will be gamma-ray pile-up, which will occur whenever a large number of gamma rays simultaneously produce secondary electrons inside the counter. The word "simultaneous" in this case means an interval short compared to the resolving time of the counter. Such pile-up is of importance in the neighborhood of piles and large accelerating machines, and also near any strong gamma-emitter.

The cross section of ordinary boron for neutron absorption is about 670×10^{-24} cm² at an energy of 0.025 ev (thermal neutrons). For enriched boron, this figure should be multiplied by 5×0.96, giving an enriched cross section of about 3,200 barns. When the neutrons to be measured are all known to have the same velocity, or when the velocity distribution is known, neutron counters will give satisfactory flux determinations. For example, the energy of neutrons present in piles is known, also that in paraffin moderators, or that emerging from various known sources. The cross section which should be used for an enriched boron counter in Eq. 3 is then that which will be obtained by substituting the velocity v into the expression

$$\sigma = 3{,}200(v/v_t) \quad (7)$$

so that the cross section can be found for any known velocity. Here v_t is thermal velocity for neutrons at room temperature, or $\frac{1}{2}mv_t^2 = 0.025$ ev, and

since this cross section is one which decreases to about 1 barn (10^{-24} cm^2) at 40,000 ev, it is evident that this energy is about the top limit for the practical use of counters which depend on capture.

Recoil counters. At higher energies, a totally different situation occurs. In the production of highly ionizing particles inside the counter, the recoil process now becomes important. The fast neutron, striking the nucleus of a gas atom, or an atom in the wall of the counter, can cause a recoiling nucleus to be ejected into the gas. Such a recoiling nucleus will have high specific ionization, usually over a short range. A counter operating by this mechanism is said to be counting recoils, or to be a recoil counter. One extremely important difference between recoil counters and disintegration counters is that recoil counters measure flux, and not densities.

If a recoil is to be highly ionizing, the neutron must have the requisite energy transmitted to it. The ability of the neutron to do this will depend on the atomic weight of the target particle, and on how central the collision was. For a completely central collision of a neutron of mass m with a nucleus of mass m_2, application of the laws of conservation of energy and momentum give

$$\tfrac{1}{2}mv^2 = \tfrac{1}{2}mv_1^2 + \tfrac{1}{2}m_2v_2^2 = E_1 + E_2 \quad (8)$$

and

$$mv = mv_1 + m_2v_2$$

where v is the velocity of the neutron before the collision, v_1 is its velocity after the collision, and v_2 is the velocity of the recoiling nucleus. Simultaneous solution of the two equations gives

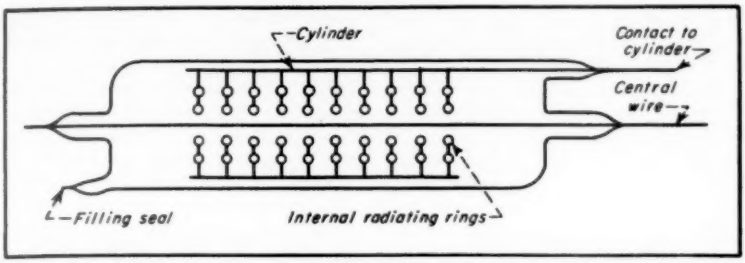
$$\frac{E_2}{E_1} = \frac{4mM}{(M+m)^2} \cong \frac{4}{M} \text{ if } M \gg m \quad (9)$$

It will be seen that energy transfer is most favorable if the masses are alike, i.e., if the target nucleus is a proton. If, for example, the recoil counter is filled with hydrogen, recoiling protons can have as much energy as the projectile neutrons. Since, on the average, it requires about 30 ev to produce one ion pair, a neutron whose energy is 30 kev will be able to produce a recoil which in turn will be able to liberate 1,000 ions. Such an ionizing event would produce a pulse easily detectible by proportional counting techniques, and easily distinguishable from that produced by, say, an electron passing through the same counter. However, if this same counter is filled with argon (mass 40) to the same pressure, the 30-kev neutron will be able to produce only a 3-kev argon recoil, assuming again a central collision. The average noncentral collision will produce a recoil of one-half this energy. The neutron energy would have to be 300 kev before a recoil capable of producing 1,000 ion pairs was produced.

The relation between the flux i and the number of recoiling atoms n_r in the gas of the counter is given by

$$n_r = VLp \int_{v_1}^{v_2} i(v)\sigma_r(v)dv \quad (10)$$

where σ_r is the recoil cross section, which again is a function of velocity. The limits of integration are determined as follows: The low limit is the lowest energy capable of being detected, as indicated by the momentum-transfer argument already given. The upper limit is that at which the recoiling particles have acquired so great an energy that they are no longer strongly ionizing and pass entirely through the counter without leaving enough ionization behind them to be observed. For an argon filling, this top limit could not be reached, for long before it was reached the target nucleus would have suffered disintegration and the assumption of an elastic collision would no longer hold. With hydrogen fillings, the limit can be reached in rare cases, but it is not often an important consideration. The recoil cross section



Counter showing arrangement of internal radiators. For recoil counters, the radiators provide source of wall recoils. For gamma counters, they increase efficiency by providing source of secondary electrons. Kind of radiator, spacing, etc., is determined by the particular problem. If of metal, potentials must be adjustable

varies slowly with energy; the value for a proton-neutron recoil drops slowly from 1.5 barns at 400 kev to 0.5 barns at 4 Mev. Hence in many energy ranges, unless the energy of the incident neutrons is completely unknown, as it seldom is, the cross section may be taken roughly as a constant. In this case integration of the equation is simple; the counting rate is directly proportional to the flux of neutrons passing through the counter.

Radiators. Because the recoil cross section is so small, recoil counters are extremely inefficient. To increase the efficiency of recoil counters, use can also be made of the recoils ejected from the walls. Indeed, additional walls can be introduced for the specific purpose of increasing the number of atoms capable of recoiling. Such additional slabs of material are called radiators, for they can be thought of as radiating recoils into the active gas of the counter. Such radiators are usually made of paraffin, this being a convenient, inexpensive substance with a high proton content.

A number of different designs of paraffin radiators have appeared in the literature, one of which is shown in the illustration on this page. The radiating elements should be comparatively thin, for recoils originating in the deep interior of any substance would use up most of their energy in getting out. Indeed, since a millimeter of paraffin has as much stopping power as a meter of air, and since the range of most recoil particles is less than a meter of air, thin radiators are clearly more advantageous than thick ones.

The computation of the number of recoils ejected from a solid into a gas is quite complicated. Modification of Eq. 10 will give another integral equation applicable to this case. Since it would be necessary to take into account whatever complex geometry the walls and the radiators had, it seems pointless to derive equations for wall recoils. However, it will in general be true that such counters measure the flux. If the velocity distribution of the neutrons is kept constant, as in monitoring applications, counting rates will give a measure of the number of fast neutrons.

Construction of Counters

Finally, a word should be said about filling procedures and manufacturing techniques. All the calculations and arguments which have been given assume that no foreign substances are present. It is especially important that this criterion cannot be a function of time. If the gas content of a counter changes, its operating characteristics

will also change, and if reliance is placed on these, then calibrations will be wrong and measurements meaningless.

Stability of a counter over a long period assumes, quite aside from the obvious assumption of no leaks, that no gas is evolved from any part of the counter surface, and that the gas within the counter shall not react with the metal or glass parts. The counters must, therefore, be properly cleaned before they are filled, and must be evacuated with good high-vacuum technique. This is usually accomplished, as is well known in the vacuum-tube industry, by repeated washing, followed by baking and pumping under high vacuum prior to filling. The gases used for filling should be pure, and pressures carefully controlled. The unfortunate fact that sloppily made or improperly pumped counters will work and occasionally work well, has resulted in many bad measurements and much poor technique becoming accepted.

The materials of which a counter is made must be selected to be nonreactive. Aluminum, for example, reacts slowly with some gases. Boron trifluoride becomes extremely corrosive when minute amounts of water or other hydrogenous substances are present. Porous or improperly baked cylinders can absorb or evolve enough gas over a period of time to alter operational characteristics considerably. Boron-trifluoride itself can be purified and should be carefully purified before it is introduced into counters. Since its freezing point is above that of liquid air and below that of an acetone-dry-ice mixture, repeated freezings and pumpings can be readily used. The importance of good techniques cannot be overemphasized.

GENERAL REFERENCES

1. S. A. Korff. "Electron and Nuclear Counters" (D. Van Nostrand Co., New York, 1945)
2. W. B. Lewis. "Electrical Counting" (Cambridge University Press, New York, New York. 1942)
3. B. Rossi, H. H. Staud. "Ionization Chambers and Counters" (McGraw-Hill Book Co., New York, 1949)
4. S. C. Curran, J. D. Craggs. "Counting Tubes" (Academic Press, New York, 1949)
5. D. R. Corson, R. R. Wilson, *Rev. Sci. Instr.* **19,** 207 (1948)
6. S. C. Curran, J. E. Strothers, *Proc. Cambridge Phil. Soc.* **38,** 654 (1939)
7. S. C. Curran, J. Angus, A. L. Cockroft, *Phil. Mag.* **40,** 36 (1949)
8. G. Brubaker, E. Pollard, *Rev. Sci. Instr.* **8,** 255 (1937)
9. S. A. Korff, *Revs. Mod. Phys.* **11,** 211 (1939); *ibid,* **14,** 1 (1942); *ibid,* **21,** 75 (1949); *Rev. Sci. Instr.* **12,** 94 (1941)
10. C. G. Montgomery, D. D. Montgomery, *Rev. Sci. Instr.* **11,** 237 (1940)
11. J. A. Simpson, *Rev. Sci. Instr.* **19,** 733 (1948)
12. W. H. Chambers, *Rev. Sci. Instr.* **19,** 476 (1948)
13. H. Slatis, *Rev. Sci. Instr.* **20,** 353 (1949)
14. W. Bernstein, R. Ballantine, *Rev. Sci. Instr.* **20,** 347 (1949)
15. T. P. Pepper, *Rev. Sci. Instr.* **20,** 222 (1949)
16. G. C. Hanna, D. H. W. Kirkwood, B. Pontecorvo, *Phys. Rev.* **75,** 985 (1949)

HUMANITY NEEDS BOTH the sciences and the humanities; both are humanizing to the extent to which they humanize. There is need for more understanding and tolerance between scientists and humanists; properly motivated all are humanists and their joint contributions can accelerate man's evolution towards intellectual enlightenment and spiritual refinement.

—*E. C. Stakman,* Research **3,** 105 (1950)

BOOKS

Phenomena, Atoms and Molecules, by Irving Langmuir, Philosophical Library, New York, 1950, xi + 436 pages, $10. *Reviewed by Vincent J. Schaefer, General Electric Research Laboratory, Schenectady, New York.*

In this book, one obtains a glimpse of the workings of the mind of one of the great scientists of our era.

As indicated in his introductory remarks (the only new contribution in this selection of Langmuir's many scientific writings), the driving force behind all of his researches has been an insatiable curiosity concerning the physical world, a tremendous supply of energy to push aside whatever barriers were encountered, and a pioneering urge to seek out the major boundaries of his subject, leaving to others the task of filling in its more detailed structure.

Although the selection of his writings was necessarily limited, (some 215 titles are listed in the bibliography) those used serve to illustrate Langmuir's method of scientific exploration, his experimental techniques—beautiful in their simplicity—and his broad grasp of scientific principles.

The nearly complete bibliography listed in the book clearly indicates the tremendous scope of his interests ranging from such topics as the philosophy of science, the structure of matter, gas-filled incandescent lamps, the mechanism of chemical reactions at high temperatures and low pressures, electron emission and space charge effects, electric discharges in gases, surface chemistry, meteorology, oceanography, submarine detection, and aircraft icing, to mention some of them.

Since this book assembles some of Langmuir's most important writings, it will be a welcome addition to the bookshelves of most scientists.

Quantitative Ultramicroanalysis, by Paul L. Kirk, John Wiley & Sons, Inc., New York, 1950, vii + 310 pages, $5. *Reviewed by David Rittenberg, Dept. of Biochemistry, College of Physicians and Surgeons, Columbia University.*

This book is a significant contribution to this extremely interesting and important branch of chemistry. The author clearly and carefully describes the general principles, procedures, and special equipment required for ultramicroanalysis (in the range of 10^{-6} grams of material). The methods described cover a wide range of substances including acid-base titrations, sodium, potassium, iron, calcium, nitrogen, chloride, phosphate, sugar, lactic acid, etc.

The portions of this book describing methods for preparing some of the equipment required are extremely helpful and are clearly illustrated by numerous figures.

This book should be useful to every experimental chemist and especially helpful to those working in the biological sciences. It is, for these times, reasonably priced.

BOOKS RECEIVED

Mathematics of Relativity, by G. Y. Rainich. This is a fairly simple presentation of the theory of relativity in which the mathematical aspect is stressed as constituting the only secure foundation for the theory. John Wiley & Sons, Inc., New York, 1950, vii + 173 pages, $3.50.

The American Roentgen Ray Society, 1900–1950. A 56-page brochure, in limited edition, containing articles and historical notes to commemorate the

(Continued on page 74)

NUCLEONIC EVENTS

FIRST NON-AEC REACTOR TO BE BUILT AT NORTH CAROLINA

The first non-AEC-owned-and-operated nuclear reactor in the United States will be built by the Consolidated University of North Carolina, using nuclear fuel loaned by the Atomic Energy Commission. The cost of the reactor, exclusive of uranium fuel, the title of which remains with the Commission, is expected to be about $100,000.

The proposed reactor, which will provide facilities for nuclear engineering research and education, will be located on the campus of North Carolina State College at Raleigh, N.C. The present design calls for a low-power reactor, having a maximum power level of 10 kw, which will use enriched fuel containing not over 1 kg of fissionable U^{235}. The North Carolina reactor will be a water-boiler type reactor, similar to one placed in operation at Los Alamos in 1944.

Design and operating studies for this reactor are under the direction of Dr. Clifford K. Beck, chairman of the physics department, North Carolina State College.

Actual transfer of fissionable material will not be made until after final approval by the AEC of safety and security provisions in the completed reactor itself, and of the plans for its operation.

Plutonium production will total less than one gram per year, an insignificant production rate in the manufacture of atomic weapons. In view of this fact, and since the reactor will be useful in the conduct of research and training itself, construction is permissible under the Atomic Energy Act of 1946.

The entire cost of the reactor will be sustained by the University. A special laboratory, to be erected with a $200,000 fund set up by the Burlington Mills Foundation, will house the reactor.

AEC NAMES BOYER AS GENERAL MANAGER

On October 25, the Atomic Energy Commission announced its selection of Marion W. Boyer to fill the post of AEC general manager which had been vacant since Carroll L. Wilson resigned on August 8 (NU, Sept. '50, p. 80). Mr. Boyer, a chemical engineer, was vice president of the Esso Standard Oil Company in charge of all manufacturing operations. Gordon Dean, AEC chairman, in commenting on the appointment, said that Mr. Boyer has "a record of outstanding success as the director of large-scale manufacturing and research operations."

This appointment was the first to be made by AEC under the new legislation which gives AEC, rather than the President, authority to hire the general manager (NU, Oct. '50, p. 96).

Carleton Shugg, who has been acting general manager since Mr. Wilson's resignation, will resume his former position of deputy general manager.

ACS ISOTOPES SYMPOSIUM PROGRAM ANNOUNCED

Speakers for the two sessions of the American Chemical Society's Symposium on Radioisotopes have been announced by John Kotrady, chairman of the symposium committee. Sessions will be held in the afternoon (2:00 to

5:00 p.m.) and evening (7:30 to 10:30 p.m.) on Friday, January 19, 1951, at the Hotel Statler, New York, N. Y. Paul C. Aebersold, chief of the AEC Isotopes Division, will be chairman of both sessions.

Afternoon-session speakers and their topics will be: Charles E. Crompton, AEC Isotopes Division, *Carbon-14 and New Frontiers of Organic Chemistry;* Charles D. Coryell, Massachusetts Institute of Technology, *Nuclear Inorganic Chemistry;* and David Rittenberg, Columbia University, College of Physicians and Surgeons, *Some Applications of Radioactive Isotopes in Biochemistry.*

The evening session will include: F. C. Henriques, Tracerlab, Inc., *The Commercial Potential of Nuclear Radiation Sources;* Paul H. Emmett, Mellon Institute of Industrial Research, *The Use of Radioisotopes in the Petroleum Industry;* and Charles Rosenblum, Merck & Company, Inc., *Principles of Radioisotopes Technology.*

NPA PRIORITY RATINGS AUTHORIZED FOR AEC

The AEC has notified the managers of its nine operational offices to apply National Production Authority priority ratings on direct contracts and purchase orders to meet authorized operations and construction programs of the Commission.

The managers were also instructed to assign to cost-plus-a-fixed-fee contractors and subcontractors the right to apply NPA ratings on subcontracts and purchase orders issued for AEC purposes.

The Commission, under authority granted by NPA Regulation No. 2, can apply these ratings on contracts and purchase orders not to exceed the following: (*1*) $34,200,000 per quarter through calendar year 1951 for operations program materials, measured in

ABOUT THE COVER

A TYPICAL, small, but well-equipped laboratory for handling radioactive materials is pictured on the cover for two reasons. First, it shows some of the instruments, materials, and accessories needed to equip such a laboratory—items which are catalogued in the "Buyers' Guide" and "Equipment Analysis Section" in the back of this issue. Second, it shows one of the laboratories recently established at Abbott Laboratories in North Chicago in connection with their isotopes program designed to aid in the pharmaceutical and medical research being done by isotope users who lack "hot-lab" facilities. This program, which is outlined on page 4 as part of an article on radioisotopes, has aroused much interest in the medical field. For instance, as a result of favorable results being reported on the use of radioactive colloidal gold for tumor therapy, Abbott has been shipping as much as 1.5 curies per week of this substance alone.
Photo from Abbott Laboratories.

deliveries, and (*2*) a total of $825,000,000 on construction programs between now and June 30, 1951, measured in *commitments*.

REACTOR SCHOOL OPENS TO 43 STUDENTS

Last month, the Oak Ridge School of Reactor Technology (NU, Jan. '50, p. 95; June '50, p. 79) opened at the Oak Ridge National Laboratory with an enrollment of 43 full-time students, representing the Atomic Energy Commission, the Air Force, the Bureau of Aeronautics, the Bureau of Ships, Bendix Aviation Corporation, General Electric Company, Westinghouse Electric Company, and several colleges and universities throughout the country.

A preliminary class, which began last March 6 with 18 trainees, is continuing with additional lectures in reactor technology and advanced training in the various divisions of the Laboratory.

ASME HOLDS FIRST MEETING OF NUCLEAR ENERGY DIVISION

The first meeting of the American Society of Mechanical Engineer's new Nuclear Energy Division was held in New York on October 31. John R. Menke, of Nuclear Development Associates, and Kenneth A. Kesselring, of Knolls Atomic Power Laboratory, spoke on the engineering applications of nuclear energy.

Two future meetings of the group, which has been organized as an activity of ASME's Metropolitan Section, are already scheduled—on February 20, 1951, there will be talks on engineering problems of nuclear energy, and on May 19, 1951, a field trip will be made to Brookhaven National Laboratory. Information about the Nuclear Energy Division can be obtained from the chairman, R. W. Cockrell, The M. W. Kellogg Company, 225 Broadway, New York 7, N. Y.

PEDIATRICIANS TO SET ISOTOPIC STANDARDS

The Isotopes Committee of the Society for Pediatric Research met on October 20 at Brookhaven National Laboratory, Upton, New York, to set up standards for protection of children receiving treatment with radioisotopes.

Members of the committee, which includes observers from the American Pediatric Society, considered standardization of safety rules and observation procedures, and discussed the feasibility of providing a central agency for correlating standard data of radiation effects on children.

Dr. Lee E. Farr, physician-in-chief of the Brookhaven hospital, is chairman of the committee.

148 AEC PREDOCTORAL FELLOWS APPOINTED

The Atomic Energy Commission announced recently that 148 new predoctoral fellows have been appointed for the 1950–51 academic year under the AEC regional fellowship program. Of the 148 new awards, 121 are in the physical and 27 in the biological sciences.

The new predoctoral fellows will carry on their studies in fields closely related to atomic energy. On completion of their work, they should be especially suited for employment by the AEC or one of its contracters.

AEC predoctoral fellowships carry a basic stipend of $1,600 in the physical sciences and $1,500 in the biological sciences, with additional allowances for dependents. Students work at institutions of their own choosing.

TRACERLAB OFFERS ISOTOPES COURSE ON WEST COAST

A training course in the handling of radioisotopes is being offered by the Western Division of Tracerlab, Inc., at Berkeley, California, for the convenience of potential users of radioisotopes

who, because of time or distance, cannot attend the courses given by the Oak Ridge Institute of Nuclear Studies.

The Tracerlab program differs from the Oak Ridge course in that the student is trained individually and intensively for two weeks and is allowed to concentrate on the techniques associated with his particular problem. A Tracerlab senior radiochemists gives one week of instruction on monitoring, handling and measurement problems. The second week of training begins with the opening of an Oak Ridge isotope container, which usually contains the same isotope that the student will use later in his own laboratory. This is followed by further instructions and practice on purification, mounting, counting techniques, and use of both flow and window G-M counters.

Because of the personalized nature of the course, the charge for it varies with the student. In general, two weeks' training costs between $400 and $500. This includes instruction time, the use of Tracerlab laboratory equipment, and the procurement and cost of the isotope that is used.

The company invites inquiries addressed to Tracerlab, Inc., 2295 San Pablo Ave., Berkeley 2, Calif.

U. OF COLORADO HOLDS COURSE ON RADIOISOTOPES

A course on radioisotopes in biology and medicine was given by the University of Colorado, Department of Medicine, on October 19–21. The program included lectures on fundamental concepts of the application of atomic energy to problems in biology and medicine. Clinical demonstrations applied these concepts to medical practice. The course was open to practicing physicians, and physical and biological scientists.

Staff members of the University of Colorado Medical Center and special guest lecturers composed the faculty.

IN BRIEF

➤*Carnegie Institute of Technology will give examinations on March 10, 1951, for ten Westinghouse scholarships worth a total of $28,500. These awards are given to highest ranking secondary school senior men for study at Carnegie in engineering, science, or industrial management.*

➤The AEC Community Study Panel recently held a two-day organization meeting. The panel was established to study the problems of introducing private ownership of real property and self-government into the AEC's three government-owned towns: Oak Ridge, Tenn., Richland, Wash., and Los Alamos, N. Mex.

➤*It was announced last month that the Knolls Atomic Power Laboratory, operated by the General Electric Company for the AEC, initiated and controlled the first chain reaction producing nuclear power in the northeastern part of the United States. The reaction was achieved in a PPA (preliminary pile assembly), which has been in regular operation since that time. PPA's, also called zero-power reactors, make possible the quick testing of mockups of different reactor designs.*

➤In a recent interview reported in the *Denver Post*, John M. Manley, assistant director of the Los Alamos Scientific Laboratory, declared that supersecrecy has hampered peacetime development of atomic energy and is one reason for industry's slowness in entering the field. He says he agrees with David E. Lilienthal, former AEC chairman, that much more data could safely be published than Congress will now allow. Among the other reasons for slowness in peacetime development, he cites the lack of personal contact between atomic researchers and industry.

➤*Construction of the AEC's $500,000 chemical processing pilot plant at Wabash River Ordnance Works in Newport,*

Indiana, was recently completed and has just undergone tests to determine if it measures up to expected performance.

➢A symposium on neutron physics was held at Brookhaven National Laboratory, Upton, New York, on November 10 and 11. The purpose of the meeting was to discuss experiments that may be performed with BNL's new reactor and further acquaint the scientists of the northeast with the laboratory's available research facilities.

➢*A new division known as the Aircraft Nuclear Propulsion Project was recently formed at the Oak Ridge National Laboratory. It was established in conjunction with Fairchild's NEPA project and the Air Force to solve the many problems connected with reactors for aircraft.*

NUCLEAR NEWSMAKERS

James L. Lawson has been appointed manager of the newly formed Electron Physics Divisions of the General Electric Research Laboratory. **Clifford G. Fick** has been named assistant manager. The divisions include the Electron Tube Division, with **E. D. McArthur** as head; the X-ray Division, headed by **Ernest E. Charlton**; the Nuclear Physics Division, of which Dr. Lawson is head; and the Communications Research Division, under Mr. Fick.

Gordon W. Newell and **Oliver D. Smith** are now affiliated with the Stanford Research Institute. Dr. Newell is senior biochemist in the Department of Applied Biology and Mr. Smith is in the Department of Chemistry and Chemical Engineering.

Donald C. Moore has been named director of the division of engineering of the AEC's New York Operations Office. A structural engineer, he became associated with the national atomic energy project in 1943 and since 1948 has been chief of the Oak Ridge Operations budget division.

Homer F. Priest, research chemist, has been appointed executive assistant to the president of the High Voltage Engineering Corporation.

Harry M. Peek has joined the staff of the Los Alamos Scientific Laboratory.

Irving Langmuir, Nobel Prize winner and recently retired associate director of the General Electric Research Laboratory, last month received the John J. Carty Gold Medal of the National Academy of Sciences.

Arthur Eldridge Focke, president of the American Society of Metals, has joined the Fairchild Engine and Airplane Corporation's NEPA Division as head of the Chemistry and Metallurgy Department.

Ellison H. Taylor last month assumed the duties of director of the Chemistry Division of Oak Ridge National Laboratory. He succeeded **John A. Swartout,** who was recently elevated to the post of assistant research director of ORNL.

Eugene Paul Wigner of Princeton University, on October 18, was awarded the Franklin Institute's Franklin Medal for his contributions in the field of mathematical physics.

George O. Robinson, director of the Office of Public Information at Oak Ridge, will be transferred to another public information post in connection with development of the hydrogen bomb. **R. W. Cook,** manager of Oak Ridge Operations Office, announced the move.

Logan B. Emlet has succeeded **S. C. Barnett** as executive director of the Oak Ridge National Laboratory. Mr. Emlet was formerly director of the Operations Division. **Mansell E. Ramsey,**

superintendent of the Pile Department has been named new director of the Operations Division.

Howard J. Curtis has been appointed chairman of the Biology Department at Brookhaven National Laboratory. He recently resigned as head of the Physiology Department of Vanderbilt University Medical School.

David A. Katcher has resigned as editor of *Physics Today*.

Ralph Carlisle Smith, assistant director of the Los Alamos Scientific Laboratory, has been appointed Lecturer in Law at the University of New Mexico. This appointment is in line with the program of cooperation planned between the university and the laboratory. Other members of the Los Alamos staff who are already associated with the Albuquerque university are **Darol K. Froman,** technical associate director of the laboratory, **Roderick W. Spence,** a group leader in the Weapon Test Division, and **Wright H. Langham,** alternate leader of the Health Division.

William H. Crew has been appointed assistant director for scientific personnel of the Los Alamos Scientific Laboratory.

Brewer F. Boardman, chief of AEC's technical information division at Oak Ridge, has taken on the additional task of adviser to the Commission's technical service in Washington.

Joseph J. Burbage, former assistant laboratory director of Mound Laboratory, was recently appointed executive director of atomic energy projects and assistant director of Monsanto's Central Research Department in charge of administration.

Raymond C. Briant was recently appointed acting director of the Aircraft Nuclear Propulsion Project, a new division of the Oak Ridge National Laboratory. **Cecil B. Ellis,** former Air Forces physicist, has been named coordinator of the ANP Project. Other recent ORNL appointments include **Theodore A. Welton,** former faculty member of the University of Pennsylvania and physicist at Los Alamos, to the Physics Division; **Daniel E. Nicholson,** of the University of Texas, to the Materials Chemistry Division; and **Marion C. Woods** from Cornell University to the Biology Division.

Sidney Krasik has been appointed manager of the physics subdivision of the Atomic Power Division of the Westinghouse Electric Corporation.

Daniel E. Atkinson has joined the staff of Argonne National Laboratory's Biological and Medical Research Division as an associate plant physiologist.

Lothar W. Nordheim, professor of physics on leave of absence from Duke University, has joined the staff of the Los Alamos Scientific Laboratory.

MEETINGS

American Physical Society—University of Chicago, Chicago, Ill., Nov. 24–25

American Standards Association, 32d Annual Meeting—Waldorf Astoria Hotel, New York, N. Y., Nov. 27–29

American Society of Mechanical Engineers, Annual Meeting—Hotel Statler, New York, N. Y., Nov. 27–Dec. 1

American Institute of Chemical Engineers, 43d Annual Meeting—Columbus, Ohio, Dec. 3–6

Radiological Society of North America, Inc., 36th Annual Meeting—Chicago, Ill., Dec. 10–15

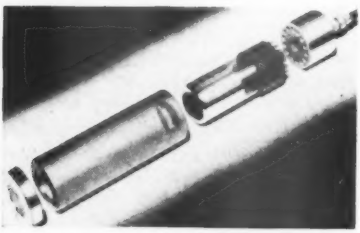
American Association for the Advancement of Science, 117th Annual Meeting—Cleveland, Ohio, Dec. 26–30

American Physical Society—University of California, Los Angeles, Calif., Dec. 28–30

Symposium on Radioisotopes, all-day session sponsored by New York Section of American Chemical Society—Hotel Statler, New York, N. Y., Jan. 19

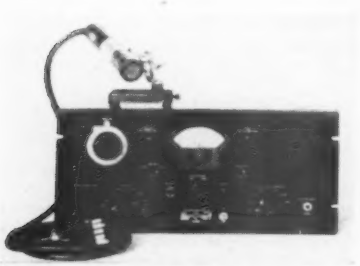
American Institute of Electrical Engineers, Winter Meeting—New York, N. Y., Jan. 22–26

PRODUCTS and MATERIALS



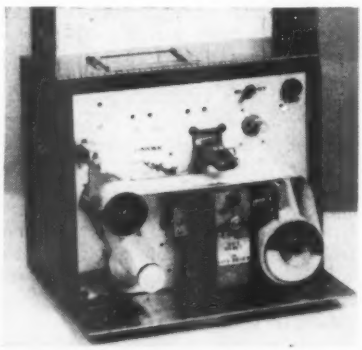
ALPHA SCINTILLATION PROBE

Tracerlab, Inc., 130 High St., Boston 10, Mass. The model P-12 alpha scintillation probe is designed for use with scalers and counting-rate meters with input sensitivities of about ¼ volt. Utilizing a phosphor and a 5819 photomultiplier, the device is said to be practically 100% efficient for alpha particles with energies of 4 to 5 Mev. Background is about five counts per hour, and almost complete insensitivity to beta and gamma radiation is claimed.



COUNTING-RATE METER

General Radio Co., 275 Massachusetts Ave., Cambridge 30, Mass. The model 1500-B counting-rate meter provides full-scale counting rates of 200, 600, 2,000, 6,000, and 20,000 cpm. The minimum rate that can be read on the meter scale is 5 cpm. Response time is variable in four steps from 1 sec to 3 min. A quenching preamplifier is built into the G-M tube probe, and it is claimed that a cable 40 or 50 feet long can be used between the probe and meter without introducing serious losses. Terminals for operating a recorder are provided. The instrument operates on 115 volts a-c, and 20% line voltage fluctuations are said to have no effect on counting accuracy.



PRINTING TIMER

Special Instruments Laboratory, Inc., 1003 Highland Ave., Knoxville, Tenn. With provisions for recording five-digit numbers plus two code symbols, the model 102 printing timer can be used either as a timer or as an impulse register. Time is recorded in thousandths of a second; maximum count is 99,999. The device can be adjusted for either automatic reset or nonreset, manual operation.

MULTIPLIER PHOTOMETER

Photovolt Corp., 95 Madison Ave., New York 16, N. Y. Series 520 multiplier photometers utilize a photomultiplier tube in a housing with a 1-in. window to detect light levels as low as 1×10^{-4} μlumen. Utilizing electronic amplification, the model 520-A gives density and light intensity readings on a logarithmic-scale meter, while the model 520-M, with 20 times higher sensitivity, has a linear-scale meter. Both models have four decade ranges, with multiplication factors of 1, 10, 100, and 1,000. Push buttons are used in the model 520-A to select the desired range.

PROSPECTING COUNTER

Nuclear Instrument & Chemical Corp., 223 W. Erie St., Chicago 10, Ill. Utilizing a neon lamp and earphones for count indications, the "Super Sniffer" is designed for use in prospecting. It is powered by two flashlight batteries and weighs less than two lb. A stainless-steel Geiger tube is used as the detector, and both beta and gamma radiation can be detected. Only control is an on-off switch. A clip is provided for attaching the instrument to the user's belt.

LEAD-GLASS WINDOWS

Penberthy Instrument Co., Hi-D Division, 666 Adams St., Seattle 8, Wash. For gamma- and X-ray protection, Hi-D glass has a lead equivalent of 0.56 and a steel equivalent of unity. Both thick and thin viewers are available. Visible light transmission through the thickest viewer produced so far, 10.5 in. thick, is 58%, and clarity is said to be excellent. With an index of refraction of 1.98, Hi-D glass provides a wide field of view.

COUNTING-RATE METER

Radioactive Products, Inc., 3201 E. Woodbridge St., Detroit 7, Mich. The pulse integrating circuit of the model C-2, 3 counting-rate meter is adjustable in five steps to full-scale ranges from 100 to 50,000 cpm. Designed for use with Geiger tubes, the instrument has an independently variable response

time that can be adjusted from 480 to 0.1 sec. Circuit linearity of better than 1% is claimed. Pulse amplitude voltage regulation is provided in the Geiger-tube power supply. Provision is made for connecting an external recording meter.

OPTICAL PYROMETER

The Pyrometer Instrument Co., Inc., Bergenfield, N. J. The Pyro optical pyrometer is a self-contained instrument for measurement of temperatures in excess of 1,400° F. Brightness of a hot body is compared with that of a calibrated electric lamp by means of a photoscreenic wedge. Temperature can be read directly on a wide scale attached to the wedge. Two lamps are furnished with each instrument; in addition, a master lamp is provided for checking calibration.

SEALING COMPOUND

Highside Chemicals Co., 10 Colfax Ave., Clifton, N. J. Made with a poly-hydroxylated plastic base, Leak Lock forms an elastic, rubbery film to seal threaded joints and gasket surfaces. Resistance to a wide range of chemicals and solvents is claimed.

BRITISH MERGER

Nucleonic and Radiological Developments, Ltd., Baltic House, Leadenhall St., London E. C. 3, England, has purchased all equipment, patents, and stock of parts for counters and associated electronic equipment from **Alltools Ltd., Brentford, Middlesex, England.** The new company will supply replacement parts from the Alltools line.

D-C MICROVOLTMETER

Millivac Instrument Corp., P. O. Box 3027, New Haven, Conn. The model MV-15A d-c microvoltmeter uses a new pulse-type d-c modulator to obtain a full-scale sensitivity of 10 μv with an input impedance of 1,000 ohms. Eleven ranges are provided, making it possible to read voltages of 0.5 μv to 1 volt. A midscale zero point is provided on two ranges for bridge measurements. Input impedance increases to 10 megohms on the higher ranges. A d-c compensation control neutralizes erratic external d-c signals. A built-in calibration circuit provides voltages for reference and instrument adjustment.

LITERATURE AVAILABLE

Hermatic Terminals. Catalog details glass-to-metal, alumina, and other terminals, and describes metallized glass seals and electronic insulators. *T. C. Wheaton Co., Millville, N. J.*

Thermocouples. Catalog 5 lists thermocouples, thermocouple wires, and protective tubes and housings. *Arklay S. Richards Co., Inc., 75 Winchester St., Newton Highlands 61, Mass.*

Hydraulic Remote Controls. Bulletin 20-105 describes single-tube hydraulic operating devices. *Sperry Products, Inc., Danbury, Conn.*

Mixing Data. Technical data sheet T-1 is a graphic compilation of power requirements for liquid agitation of most types. *Process Industries Engineers, Inc., 5941 Baum Blvd., Pittsburgh 6, Pa.*

Radiation Instrument Catalog. Divided into two volumes for convenience in handling, Catalog No. 2 lists survey meters, monitors, personnel protection instruments, scalers, accessories, and special components. *U. S. Atomic Energy Commission, Technical Information Division, Oak Ridge, Tenn.,* **$2.00.**

REFLECTIONS

Educators' Judgments

DEAR SIR:

The following data on educators' judgments on an effective program for atomic education may be of interest to NUCLEONICS' readers.

Three Groups of Data. In October, 1949, a group of college presidents and science writers were asked:

1) How important is it, in your opinion, for the American public to be well-informed with respect to: *a*) basic science of nuclear fission; *b*) peacetime possibilities of atomic energy; *c*) suggestions and possibilities for international control of atomic energy?
2) Particularly with respect to international control, what do you think might be done to further public information and understanding?

In February, 1950, 97 high-school science teachers and administrators who had attended a two-day seminar on educational problems in this field were asked to indicate how important they thought it was for the "general public" and "high-school students" to be informed on each of 21 "special aspects of the general subject of atomic energy, which are included more or less regularly when the subject is presented as part of an educational program." They were also asked to indicate how much material they thought available.

In May, 1950, a group of 67 high school teachers made the same judgments in their schools.

With respect to the first question, the consensus is that it is important for the public to be informed on all three topics. Where differentiation is made among them, the ranking given most often is: international control, peacetime applications and, of least significance, basic science. One person in six said that it is more difficult to get across the concepts of basic science.

The secondary school teachers and their supervisors, who made more quantitative judgments in February, 1950, also tended to stress the social rather than the physical science topics. The first seven aspects, ranked in descending order according to the number of people who said it was essential for the "general public" to be informed on them, were:

1) Relations between science, technology, and social change
2) Problems of international control
3) American program for development and control of atomic energy
4) Radiation: what it is and what effects it has on human beings
5) AEC problems—secrecy vs free dissemination of knowledge
6) Civilian vs military control of atomic energy
7.5) Development of atomic energy abroad
7.5) Application of nuclear energy to medicine

Topics judged least important were:

16) History of the Manhattan Project
17) Engineering and economic problems of electricity from nuclear power
18.5) Nuclear energy for the propulsion of ships
18.5) Nuclear energy for the propulsion of aircraft
20.5) Historical evolution of nuclear physics
20.5) Theory and methods of producing radioisotopes

Approximately the same order prevailed for the significance of each topic for "high school students."

The group of teachers who were asked to make judgments in May, 1950, differed from this group in two major respects: (1) they were not active participants in a workshop on atomic energy; (2) they represented all curriculum fields where the earlier group was composed solely of science teachers. However, the trend was to emphasize the same topics, ranked only slightly differently, for the "general public."

This group also saw a very high (+0.92) correlation between the needs of the "general public" and those of "high school students."

Information Techniques. The members of the college president-science writer group were asked for suggestions on how to explain the particular prob-

lem of international control. Of the 92, 42 thought the major responsibility should be taken by the mass media of communication—radio, newspapers, magazines, television and comic books; 19 stressed inclusion in school curricula at all levels. The other frequent suggestion was community club programs.

Even if we were to assume agreement on two major techniques—introducing material into curricula at all levels and encouraging the mass media of communication to spend more time (and space) on atomic energy—the fact remains that there is a major discrepancy between what is judged to be important and what is judged to be available. Science writers and classroom teachers may be willing to emphasize this material but do not think it is accessible.

The rank-order correlation between "important for the general public" and "available" for the February group of science teachers was +0.12. The second group of teacher judgments yielded a correlation of +0.57. It is suggested that the people who had recently been working in the field tended to feel that what was most important was not necessarily most readily available. On the other hand, the teachers with more casual acquaintance with the field were more likely to say that what is available must be most important.

A summary of these data and their implications seems to be:

A. There is agreement that it is more important for the general public to know about applications and social implications of the release of nuclear energy than it is for them to understand the technical aspects of nuclear science.

B. It is the judgment of teachers who are interested in the field that there is not as much material available in these areas as is desirable.

The fallacy of a purely physical-science approach to atomic education is becoming clear. It is supplemented by another fallacy: the idea that social science is easier to comprehend than physical science. In February, 1949, 302 New York University students were asked to answer twelve multiple choice questions about physical and social aspects of atomic energy. The topics of the questions, with the percentage of students giving the correct answer, are listed below:

$E = Mc^2$	90%
Chain reaction	82%
Fissionable materials	62%
Critical mass	60%
Tracers in medical research	50%
Research on atom-powered ship	48%
Manhattan Project as wartime code name	44%
Acheson-Lilienthal report	24%
Date of splitting of uranium atom	14%
F. H. Osborn as U.S. delegate to U.N. AEC	10%
Length of time U.S. AEC has functioned	6%
Is General Groves a member of U.S. AEC	4%

These were all advanced students in a liberal arts college who, presumably, had had introductory courses in both social and physical science. As they pointed out, *once they learned the physical-science facts, they were well informed until some major new development was announced, but the current events material is difficult because it changes rapidly.*

Implications for a Program. These data lead to the following suggestions for any program of public information:

1. Emphasize the social—particularly international and economic—aspects of the problem. These can be presented in terms of broad principles so that the person will feel better able to understand current events.

2. Applications should be presented first in terms of "what these developments mean to you" and secondarily in terms of the scientific processes.

3. The physical scientist will need some help with this project. Other fields of educational effort must cooperate to present material effectively.

LILLIAN WALD KAY
Department of Psychology
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